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Prof. W. M. Davis
with kind regards
I. C. Russell

DEPARTMENT OF THE INTERIOR—U. S. GEOLOGICAL SURVEY
J. W. POWELL, DIRECTOR

EXISTING GLACIERS

OF THE

UNITED STATES

BY

ISRAEL C. RUSSELL

[EXTRACT FROM THE FIFTH ANNUAL REPORT OF THE DIRECTOR, 1883-'84.]

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EXISTING GLACIERS

OF THE

UNITED STATES.

BY

ISRAEL C. RUSSELL.

Boutwell 15

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EXISTING GLACIERS OF THE UNITED STATES.

By Israel C. Russell.

WHAT IS A GLACIER?

Glaciers have become ss well known from the graphic descriptions of Carpenter, Forbes, Agassiz, Tyndall, and other explorers, that it seems unnecessary at this time to do more than call attention to a few of their more characteristic features by way of an introduction to what I have written concerning those now existing in the United States.

The formation of glaciers in any region depends primarily on the fact that the amount of snow precipitated during a term of years exceeds the amount dissipated by melting and evaporation. In this manner snow banks of broad extent are formed, the lower portions of which become compacted into ice. The change from snow to ice is known to result from pressure, and as ice is mobile under pressure, either by reason of its inherent plasticity or as a result of regelation, the weight of this mass tends to change its form, and it thus acquires motion, which takes the direction of least resistance.

The essential characteristic of glaciers seems to be that they result from the consolidation of snow in regions of secular accumulation, *i. e.*, above the snow-line, and flow to regions of dissipation, *i. e.*, below the snow-line. From these primary conditions result a multitude of secondary phenomena.

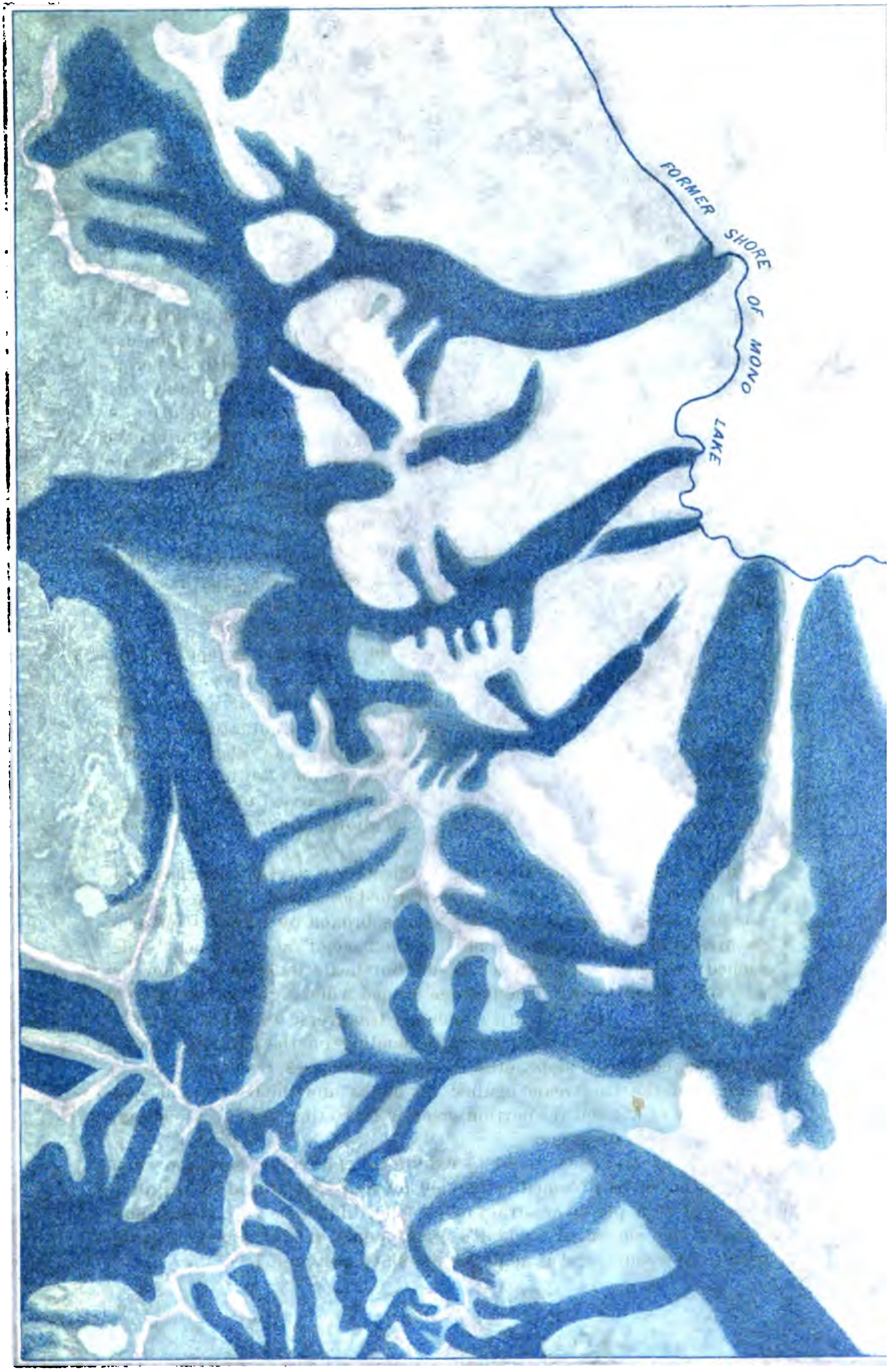
For convenience of reference we will divide glaciers into *alpine* and *continental;* not that the two classes are always distinct and separable, but for the reason that typical examples of each are well characterized and capable of specific description. Variations occur in each class which may suggest minor subdivisions.

The glaciers with which we are most familiar belong to the class that have their archetype in the mountains of Switzerland, and occur about high peaks, usually in amphitheaters or *cirques* at the heads of high-grade valleys. The snow that accumulates on high mountains, especially in temperate latitudes, is frequently not completely melted during the summer, and thus tends to increase indefinitely. The *névé* of a glacier is such a snow-field. The gorge or valley leading from every alpine amphitheater furnishes an avenue of escape for the consolidated *névé*-snow, which is forced out through the opening, and flows for a greater or less distance as a stream of ice. Such in brief is the genesis of an alpine glacier. Every glacier of this class is divided into a *névé*, or snow region, above and an icy portion below. The line of demarkation is the *snow-line.* As compact ice occurs also beneath the *névé* from which it is formed, this division of a glacier into two portions applies only to the surface. The division line, moreover, shifts with the seasons; at times, perhaps for many years together, the true glacier ice may be concealed by a snowy covering. The *névé* is composed of granular snow, white or grayish-white in color, and comparatively free from dirt and stones; below the snow-line the glacier is formed of both porous and compact ice, and is usually concealed more or less completely with rock débris. From a distance these two divisions are frequently distinctly shown by contrast in color. The stones and dirt that fall on the *névé* sink more or less deeply into the snow and become buried beneath the next addition, and as the *névé* becomes consolidated and acquires glacial motion, this débris is carried along in its mass. But the region below the *névé* being one in which loss exceeds supply, the snow and ice are melted, and the foreign bodies formerly held in the mass become concentrated at the surface, and are then carried along as moraines. Thus in the *névé* region the tendency is to bury foreign objects, and in the glacier proper to concentrate them at the surface.

All the débris carried by glaciers may be designated in general terms as *morainal* material, but when arranged in definite ways it receives specific names. When distributed along the margin of an ice-stream it forms *lateral* moraines. Two glaciers uniting, the right lateral moraine of one combines with the left lateral moraine of the other to form a *medial* moraine at the line of contact, the ice-streams flowing on side by side as a single compound glacier. The débris carried to the extremity of a glacier and deposited about its foot is known as a *terminal* or *frontal* moraine.

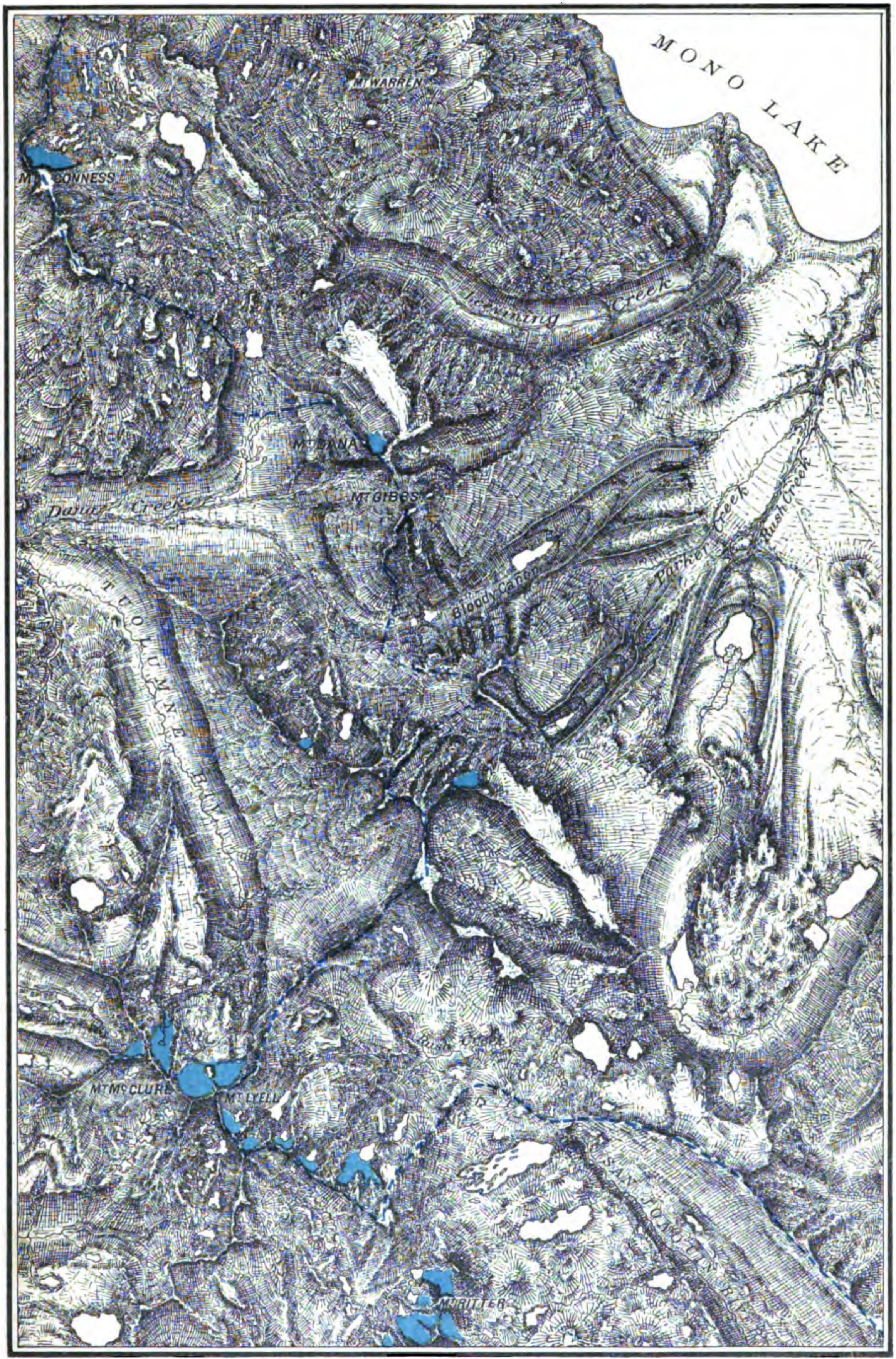
In flowing through a valley ice is subjected to stress, which causes it to fracture and form open fissures termed *crevasses.* When a glacier passes over a steep descent it becomes broken by a great number of fissures, and not infrequently falls to the base of an escarpment in detached blocks, forming an ice cascade, but heals its scars and flows on as a solid mass below. The fissures formed when a glacier passes over an inequality in its bed are commonly transverse to the direction of flow, but may take other courses, depending on the nature of the obstruction, change of slope, etc. Marginal crevasses, resulting from the friction of the ice-stream against its banks and the consequent more rapid flow of the central portion, usually leave the shore at a moderate angle and tend up-stream.

Glacier ice has been found to exhibit a definite structure, known as lamination, or as ribboned or banded structure, produced by the alternation of thin plates or strata of compact bluish ice with others more porous. As shown by Tyndall's experiments, this arrangement is the result of pressure, and is analogous to slaty cleavage.



FORMER GLACIERS OF THE SIERRA NEVADA.

Névé Region Glaciers ■



W. D. Johnson, Topographer

Julius Bien & Co. Lith

I. C. Russell, Geologist.

EXISTING GLACIERS OF THE SIERRA NEVADA.

Glaciers ■ Scale 1 inch = 2.5 Miles Pacific and Great Basin divide — —

Scale of Miles.

1 2 3 4 5 6 7 8

Owing to unequal melting, the surface of a glacier is usually extremely irregular, the parts protected by moraines standing in higher relief than the clearer portions. Still further diversity is formed by bowlders perched on columns of ice, which they have protected from melting as the general surface wasted away. These are termed *glacial tables.* At other times the ice bristles with a multitude of acicular pyramids, or is melted into holes and ice-wells, each having a stone or mass of dirt at the bottom.

The melting of the surface of a glacier gives rise to many rivulets and brooks, which course over it in channels of ice, frequently plunging into yawning crevasses, and finally joining the subglacial stream that issues from beneath every glacier. These glacier-born streams are always heavy with comminuted rock, ground fine by the moving ice.

Such in brief are the principal characteristics of alpine glaciers.

At the present time continental glaciers are confined to the arctic and antarctic regions, and have been less thoroughly explored than the alpine forms common in more temperate latitudes. Glaciers of this class are characterized by their broad extent and by not being confined by definite walls; their *névés* are large, frequently covering nearly the entire glacier, and their surfaces are free from bowlders and débris, for the reason that they are regions of accumulation, and also because mountains seldom rise above them. Owing to inequalities in the country over which these great fields pass, they are not infrequently broken by crevasses; and as on smaller glaciers the melting of the surface gives origin to numerous streams, frequently of large size, which become ponded and form lakes in basins of ice or plunge into open fissures and disappear in the body of the glacier. Existing continental glaciers are believed in all cases to flow from the interior towards the coast, and hence may be considered as acquiring motion in all directions from a center of accumulation. When alpine glaciers increase sufficiently to cover an entire mountain range and form a confluent ice-sheet, they approach and may pass into the continental type. It is not impossible that a mountain range of very modest dimensions might give origin to a quaquaversal glacier of vast proportions. It is perhaps not out of place to suggest in this connection that the glaciers which formerly covered the New England States and Canada were of this character.

In framing a definition of a glacier it is evident that we must include both alpine and continental types, and also embrace the secondary phenomena that are commonly present. A glacier is an ice-body originating from the consolidation of snow in regions where the secular accumulation exceeds the dissipation by melting and evaporation, *i. e.*, above the snow-line, and flowing to regions where loss exceeds supply, *i. e.*, below the snow-line. Accompanying these primary conditions many secondary phenomena, dependent upon environment, as crevasses, moraines, lamination, dirt-bands, glacier-tables, ice-pyramids, etc., may or may not be present. Thus, glaciers even of large size may exist without moraines; in such an instance glacier-tables, ice-pyramids, ice-wells, etc., would be absent. We may conceive of a glacier flowing through a channel so even that it would not be broken by crevasses, but such instances must be extremely rare. The most common of the numerous secondary features seems to be the laminated structure of glacial ice, but even this is not always distinguishable in ice-bodies that are unquestionably true glaciers.

Although the definition we have presented may assist in understanding the nature of a glacier, yet it is manifestly open to objections. If we consider the snow-line as defining the limit between the *névé* and the glacier proper, it is evident that there must be numerous exceptions to the rule. As before remarked, during certain years, and in many instances for a term of years, the snow-line is much lower than at other times, and may completely conceal the glacier beneath. Again, an ice-stream may terminate in the sea and be broken up and form icebergs before the differentiation into *névé* and glacier proper has been reached.

From all that has been determined concerning the nature of glaciers it is evident that they form one of the transition stages in the history of the snow that falls in certain regions, and like genera and species in the organic kingdom cannot be limited by hard and fast lines, but may be classified by comparison with typical examples. From the snow, hail, and frozen mists of a mountain-top are formed the accumulations of granular ice-snow which we call a *névé*. By pressure and alternate melting and freezing, the *névé* passes into compact ice, which acquires motion and is termed a glacier; but the plane of separation is indefinite, and one merges into the other by insensible gradations.

A word in reference to the records inscribed by glaciers on the country they occupy, and we will pass to the immediate subject of our essay.

The morainal material carried by glaciers is deposited when melting takes place, and frequently forms characteristic accumulations that still retain the name of moraines. The débris along the border of an ice-stream is frequently left as ridges or irregular terraces on the sides of a valley, marking the former height of the ice flood. At various stages in the retreat of the ice the lateral moraines are united by terminal moraines, which cross the former bed of the glacier in irregular but usually crescent-shaped piles, between which the valley bottom is usually deeply filled with unassorted débris, and frequently occupied by lakelets. When a glacier is prolonged from the mouth of a valley on a plain, it builds out its lateral moraines perhaps for many miles, and when it retreats these are left as parallel embankments, not infrequently hundreds of feet high and sometimes miles in extent.

The movement of glaciers causes friction, which results, as the study of living glaciers has shown, in the smoothing and scratching of the rocks over which the ice passes. The bowlders, pebbles, and sand held in the bottom and sides of the glacier produce smoothed and polished surfaces, crossed by scratches and grooves having an exceedingly characteristic

MOUNT DANA FROM THE SOUTH.

appearance, which, when once understood, it is difficult to mistake for the results produced by other agencies. While the rocks beneath a glacier are being worn and rounded, the stones set in the ice are in turn battered and scratched and often ground down to plane surfaces that are not infrequently polished and covered with glacial striæ.

As a rule, alpine glaciers follow pre-existing drainage valleys, which they enlarge and broaden. As frequently stated, a stream-cut gorge is distinctly V-shaped, but after being occupied by a glacier it is found to have become U-shaped in cross-section.

The records of glacial action looked for by geologists are: deposits of morainal material, which frequently differs from the adjacent country rock, and may occur in an irregular manner or be grouped definitely as lateral and terminal moraines; bowlders perched in fortuitous positions, as on steep slopes and hill-tops; smoothly rounded rocky knolls; polished and scratched rock surfaces; rock-basins, etc.

With this elementary sketch to refresh the memory I propose to present in a somewhat popular form such observations as are attainable in reference to the existing glaciers of this country. In this connection, as the sequel will show, we have to deal solely with glaciers of the alpine type.

EXISTING GLACIERS OF THE SIERRA NEVADA.

The Sierra Nevada, by far the grandest of the mountain ranges of California, attains its greatest elevation between latitude 36° and 38° 30′, or, in a more general way, between Owen's Lake and Lake Tahoe.

To the more elevated region in this portion of the range the name of High Sierra was applied by the geologists of the California survey. Although the boundaries of the region thus designated are indefinite, it is well worthy of special distinction, as it is a prominent and important topographic feature. Throughout its entire extent it bristles with rugged peaks, narrow crests, and inaccessible cliffs overshadowing profound chasms, all of which combine to form one of the most rugged and picturesque mountain masses on the continent. The culminating point in this elevated region is near its southern limit, where Mount Whitney rises to an elevation of 14,448[1] feet above the sea and is succeeded as one goes northward by Mount King, Mount Humphreys, and many other mountain masses scarcely less magnificent. In the neighborhood of Mono Lake a number of the more prominent peaks, of which Mounts Lyell, Ritter, and Dana, and Tower peaks are examples, exceed 13,000 feet in elevation. Southward the Sierra declines rapidly, and the range is considered as terminating in that direction at Tehichipi Pass, a little north of latitude 35°. Northward of Mount Whitney there is a vast sea of rugged peaks and narrow mountain crests, separated by profound cañons, which render the region all but inaccessible to beings not equipped with wings. This is the High Sierra *par excellence*, as all will admit who have attempted to scale its dizzy peaks or thread its labyrinth of cañons. The range retains this rugged character all the way to Sonora Pass, and even to Lake Tahoe, but northward of that "Gem of the Sierra" the mountains are less elevated.

Very large portions of the High Sierra are composed of light-colored granite, which is commonly thinly clothed with vegetation, and imparts a cold gray tone to the rugged scenery. The peaks and crests overlooking Mono Lake, however, have been sculptured from somewhat metamorphosed sedimentary rocks, which have been penetrated by heavy beds of intrusive granite, and are frequently rich in color. The landscape in this portion of the range is in pleasing and striking contrast with the gray monotony of the western slope, and exhibits innumerable shades and tints which combine to form pictures as rich in tone as they are grand in proportions. The deep longitudinal valley lying in the

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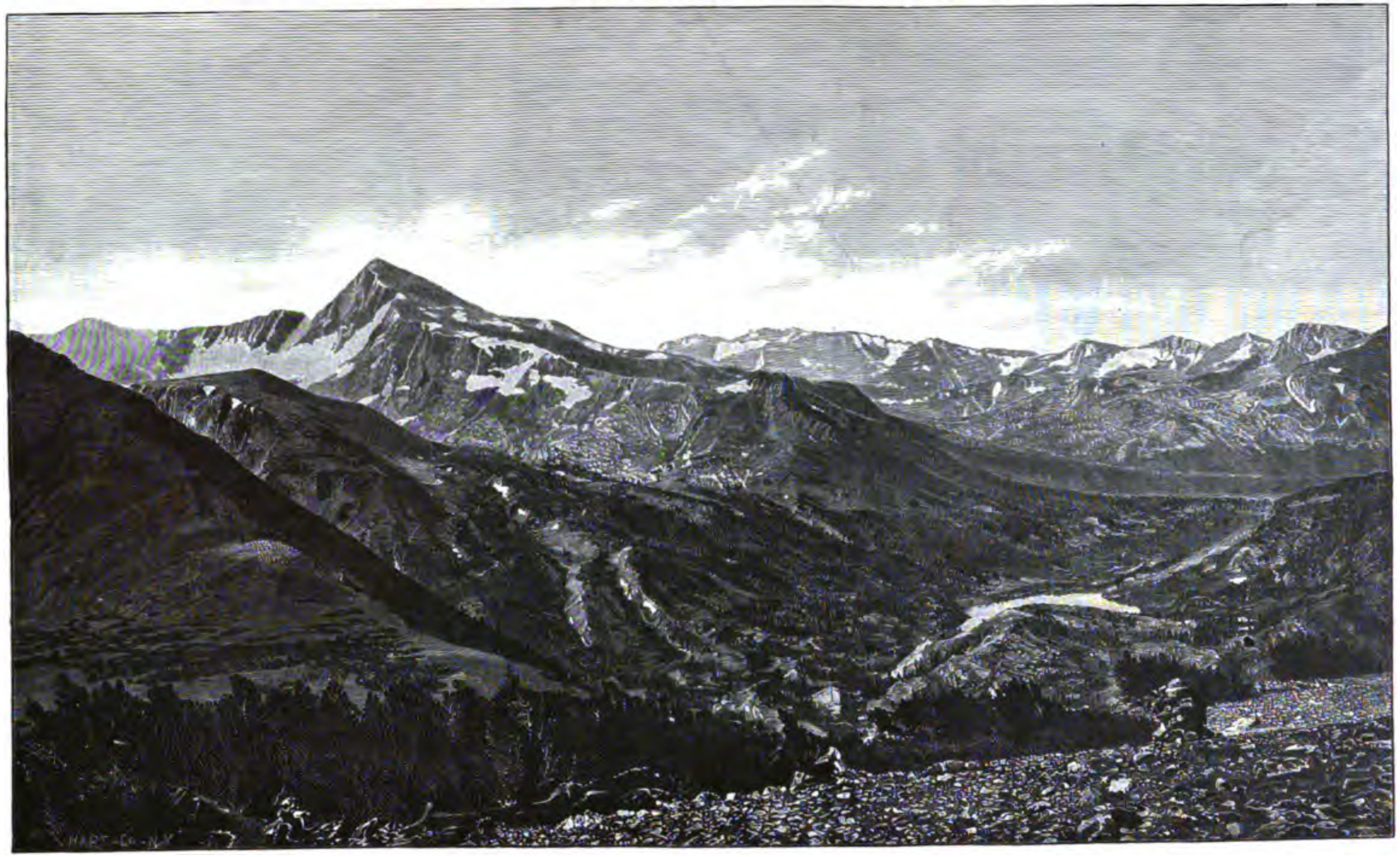
[1] Surveys West of 100th Meridian, Vol. II, p. 566.



MOUNT DANA FROM THE WEST.

crest of the range to the southward of Mount Dana is especially noteworthy for the beauty of its scenery, and deserves to be named in remembrance of some of the old Flemish masters, so deep and rich are its colors.

Besides the splendor of alpine scenery the mountains to the southward of Mono Lake present the additional attraction of living glaciers, which, although small, are well worthy the careful attention of every traveler.

PERSONAL OBSERVATIONS.

Existing glaciers on Mount Dana and Mount Lyell were visited by Mr. G. K. Gilbert and myself during the summer of 1883; I also examined one at the head of Parker Creek, a tributary of Mono Lake; others on Mounts Conness, McClure, and Ritter were explored by Mr. Willard D. Johnson, my companion and assistant, while making a topographical survey of the region draining into Mono Lake. Besides the glaciers actually examined, a number of others were seen from commanding points and their general nature was as thoroughly understood as if their surfaces had actually been trodden. Our combined observations have shown that nine glaciers now exist within the southern rim of the Mono Lake drainage basin; while a somewhat larger number are to be found among the mountains of which McClure, Lyell, and Ritter are the dominant peaks, and from which flow the Tuolumne, Merced, and San Joaquin Rivers.

The glaciers of the High Sierra are located between latitudes 36½° and 38°, and have an approximate elevation of 11,500 feet above the sea. The lowest seen was on the northern side of Mount Ritter, and terminates in a lakelet that is about 2,000 feet below the mountain top, or approximately 11,000 feet above the sea. The glaciers observed are all small, the most extensive—that on the northern slope of Mount Lyell—being less than a mile in length, with a somewhat greater breadth. Nearly all occur in amphitheaters or *cirques* on the northern sides of lofty peaks, where they are sheltered by high cliffs and mountain ridges, and all flow northward, excepting a few seen in deep *cirques* on the eastern side of the Minarets and Mount Ritter; so far as known these are the most southerly of any in the United States. Snow-fields are reported by Mr. Johnson, however, as existing in the mountains to the southward of Mount Ritter, at the head of some of the many branches of Owen's River. If these prove to be veritable glaciers they will extend the southern limit of the existing glaciers of this country, a few miles farther southward.

MOUNT DANA GLACIER.

On the western shore of Mono Lake the mountains rise abruptly from the water's edge to an elevation of 5,000 or 6,000 feet, and have been sculptured by storm and frost into many independent peaks of remarkable grandeur. As seen from Mono Lake, the most conspicuous point along the mountain crest is Mount Dana, which rises 6,500 feet above the lake and has an elevation of 13,227 feet above the sea.[2] Although of grand proportions, the peak is but one among many which form the crowning points on the divide separating the drainage of Mono Lake from that of the Pacific. From the southward Mount Dana presents a somewhat rounded contour, as shown in Plate XXXIII, and is easy of ascent; on the north, however—as may be judged from Plate XXXIV, which shows it in profile, the view being eastward from the divide between the mining camps of Tioga and Lundy—it forms a nearly perpendicular face more than a thousand feet high. This northern face descends into a deep narrow cañon leading northward, which we have named Glacier Cañon. In the illustration forming Plate XXXIV a partial view of this gorge is obtained, as well as a glimpse of the *névé* of the Dana Glacier which occurs at its head. During the Glacial epoch the whole extent of this cañon was occupied with ice, which formed a tributary of the ancient Leevining Creek Glacier and flowed into the Mono Lake basin. The valley formerly occupied in part by this glacier is seen in the foreground of the illustration. In Plate XXXV a general view of nearly the entire Dana Glacier is presented as seen from the moraine at the lower side of the lake of milky opalescent water that lies at its foot. The moraine now forming can be seen curving about the end of the glacier, while small crevasses are observable at the right. The glacier is perhaps 2,000 feet long in the direction of the flow, but appears much foreshortened in the illustration. "Ice tongues" are seen extending upward from the *névé*. At the base of the largest of these a portion of a wide crevasse is visible. Plate XXXVI is a nearer view of the same glacier, in which the minor features are more cleary defined. Plate XXXVII exhibits the end of the glacier, and shows the extremely rugged nature of the ice surface; narrow dirt bands, sweeping in undulations across the terminus, are also visible.

MOUNT LYELL GLACIER.

In traveling from Mount Dana to Mount Lyell one finds it most convenient to pass down Dana Creek to its confluence with the Tuolumne, and then ascend the deep broad-bottom cañon of the latter stream, which leads directly to the Lyell Glacier, at the foot of which the river has its birth. Plate XXXVIII presents a view of the snowy summit of Mount Lyell as seen from near the head of the Tuolumne Cañon. The majestic mountain as seen from this portion of the valley is far more grand and beautiful than any illustration in black and white can suggest. In the soft gray light of morning it has all the solemn grandeur of the Bernese Oberland, and at sunset, when flushed with the rosy light of the afterglow, this shrine of the High Sierra rivals the splendor of Mount Rosa. To the right of Mount Lyell rises Mount McClure,

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[2] Elevation of Mono Lake determined from railroad levels; height of adjacent peaks measured by angulation.

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[illegible]

[illegible]
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of grand proportions [illegible]
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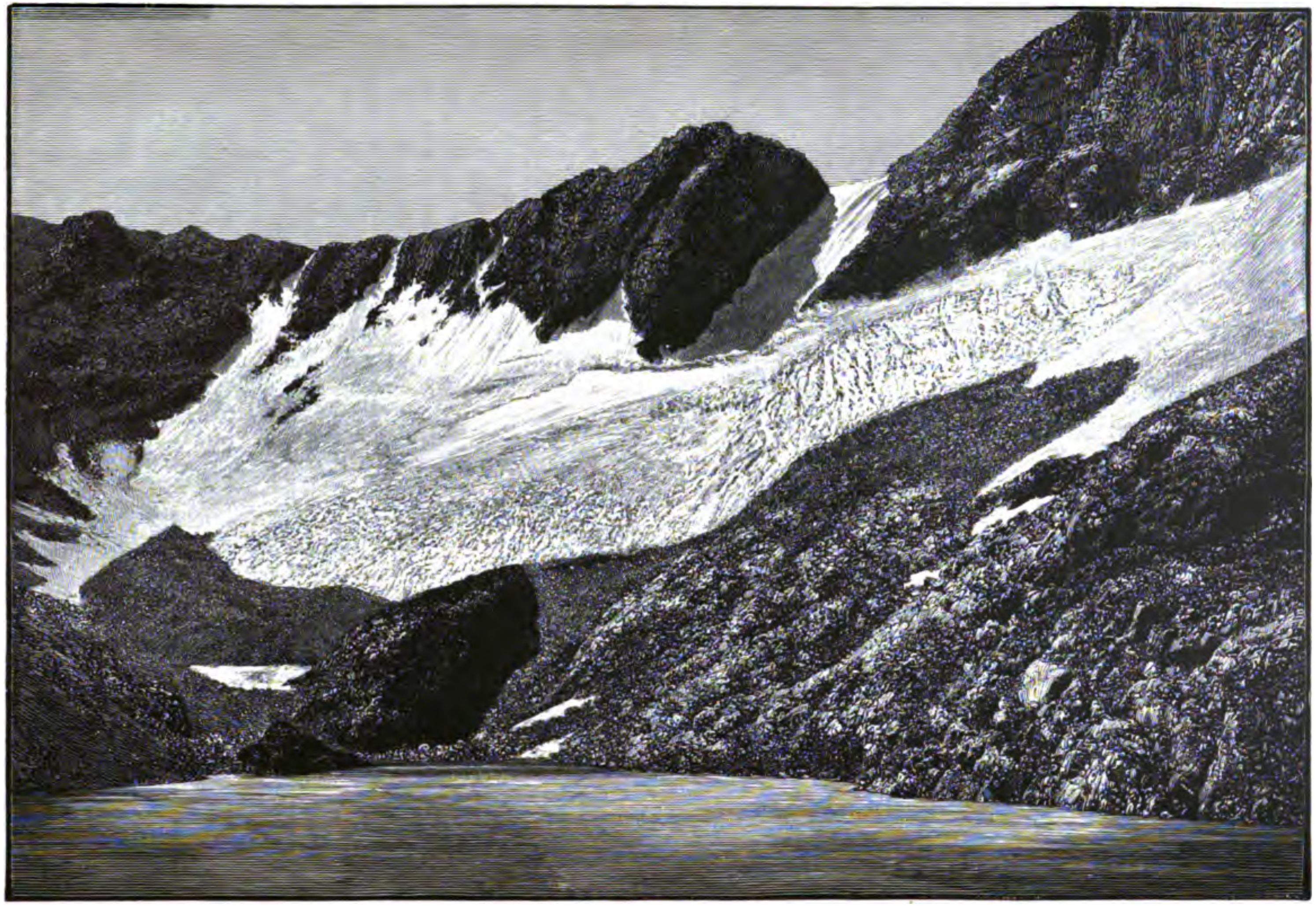

MOUNT DANA GLACIER.

which is scarcely less grand than its companion; the former attains the height of 13,217 feet above the sea and the latter is 150 feet less in elevation.

The Tuolumne Cañon, when followed still nearer to its beginning, is found to lose its gentle grade and become rugged and precipitous, being crossed at intervals by irregular cliffs, that must have caused magnificent ice-cascades in the great glacier that once flowed over them. The top of each steep ascent is usually separated from the base of the next higher one by a comparatively level tract, sometimes holding a swampy meadow. This succession of cliffs and terraces forms a grand stairway, leading up to the opening of the amphitheater on the northern side of Mount Lyell, whence a magnificent panorama of the entire glacier may be obtained. The view given on Plate XXXIX is from near the outlet of the amphitheater, and will assist in interpreting the map of the Lyell Glacier given on Plate XL. In the panorama the moraine now forming at the foot of the glacier is well shown, as is also the rounded rock-mass that rises as an island in the central portion of the glacier; the crevasses and contorted dirt-bands at the foot of the ice, although noticeable features when seen in nature, are but indifferently represented in the illustration. A view down the cañon of the Tuolumne is presented on Plate XLI, as an illustration of the height on a side of the valley attained by the ancient glacier; by estimate the terrace marking the upper limit of the ice river is about 2,500 feet above the present bed of the Tuolumne.

PARKER CREEK GLACIER.

This glacier is situated at the head of the deep, high-grade cañon through which Parker Creek descends to the valley of Mono Lake. It is smaller than the ice-bodies on Mount Dana and Mount Lyell, but is yet a true glacier ,with a well-defined *névé* region, from beneath which descends a mass of ice that is crossed by dirt-bands and crevasses, and has many of the minor features characteristic of glaciers. About the foot of the ice there are huge moraines, forming concentric ridges, which in mass must far exceed that of the glacier as it exists at the present time. These moraines are more characteristic examples of the tumultuous débris piles formed by ice-action than any other recent deposits of the same nature seen in the High Sierra. Like the majority of the glaciers in this region, the one at the head of Parker Creek is sheltered by the walls of an amphitheater, and flows northward. During the Glacial epoch the entire extent of Parker Creek Cañon was occupied by a glacier which descended upon the Mono plain and built huge embankments more than a mile in length, which are only second in interest to the similar deposits at the mouth of Bloody Cañon.

GLACIAL PHENOMENA.

That the ice-bodies observed in the High Sierra, although small, are yet veritable glaciers, I trust will appear from the following somewhat detailed statement of observations.

Névé and glacier.—The distinction between *névé* and true glacier ice is plainly manifest in the Sierra Nevada glaciers, not only when viewing them from a distance, but also while traversing their surfaces. In the case of the Parker Creek Glacier especially, the change from the granular snow of the *névé* to the compact ice of the glacier can be discerned within the space of a very few feet.

The *névé* is invariably white as compared with the rest of the glacier, and is composed of granular ice-snow. Its surface is almost entirely free from stones and dirt, and is rendered very rough and uneven by crests and spires of ice from 2 to 5 feet high that result from the unequal melting of the surface. These "ice-blades" have been described by Le Conte,[3] who refers their origin to the unequal melting of wind-rippled snow.

At its lower limit the *névé* passes into the glacier proper—which in part it overlies—and acquires a ribboned or laminated structure, dirt-bands, etc., characteristic of a true glacier. A protrusion of compact ice below the *névé* was observed in all the glaciers seen in the High Sierra.

Crevasses.—Marginal crevasses were observed in numerous instances, but they occur in quite limited numbers in any individual glacier. In some examples the marginal crevasses in the *névé* region were convex toward the head of the glacier, while others farther down in the same series had become straight, or had changed their curvature so as to be concave upward. A series of crevasses illustrating this change is shown in the central portion of the map of the Lyell Glacier, forming Plate XL. The crevasses seen most commonly occur near the head of the *névé* and correspond to the "bergschrund" of Swiss mountaineers. These vary from narrow cracks up to chasms 6 or 8 feet wide, which frequently cross almost the entire breadth of the *névé* and often render the passage to the rocks above extremely difficult. The depth of the crevasses could seldom be determined, the irregularities of their sides limiting the view; but some were certainly not less than 100 feet deep. The crevasses at the head of the *névé* were frequently arched with snow and hung within with vast numbers of smooth icicles. The walls beneath these treacherous roofs were incrusted with large masses of well-formed *ice-crystals*, which exhibited flashing faces half an inch in diameter and resembled the most beautiful transparent spar. The light in these fairy-like grottoes was of the most exquisite blue.

Lamination or ribboned structure.—This structure was seen in all the glaciers closely examined, but appeared most conspicuously near the lower extremity of the ice, where the lamination was approximately horizontal. Hand specimens cut from the ice exhibited sections of alternating narrow bands of compact blue ice and porous white ice as plainly as could be desired.

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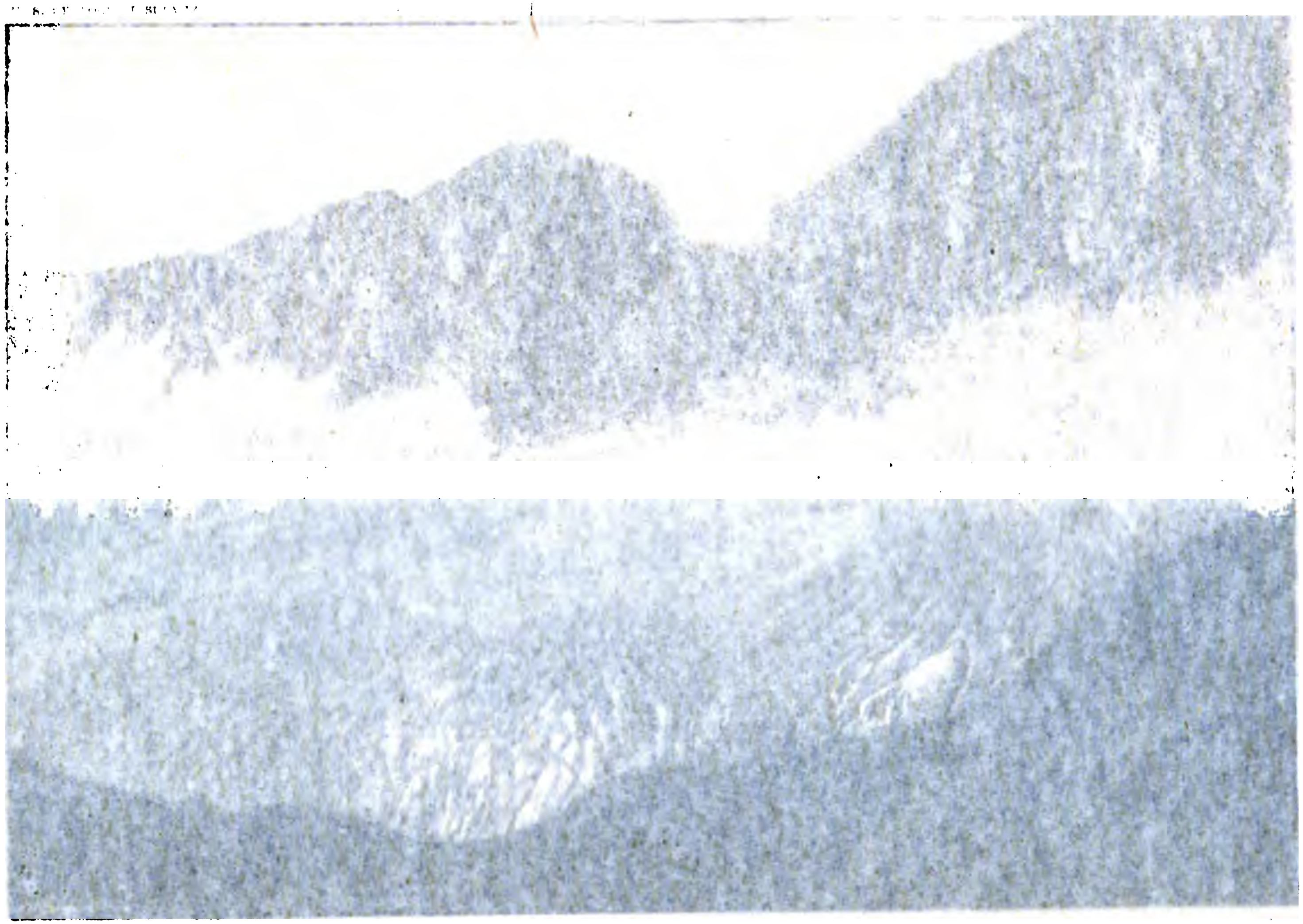
[3] Postea, page 325.



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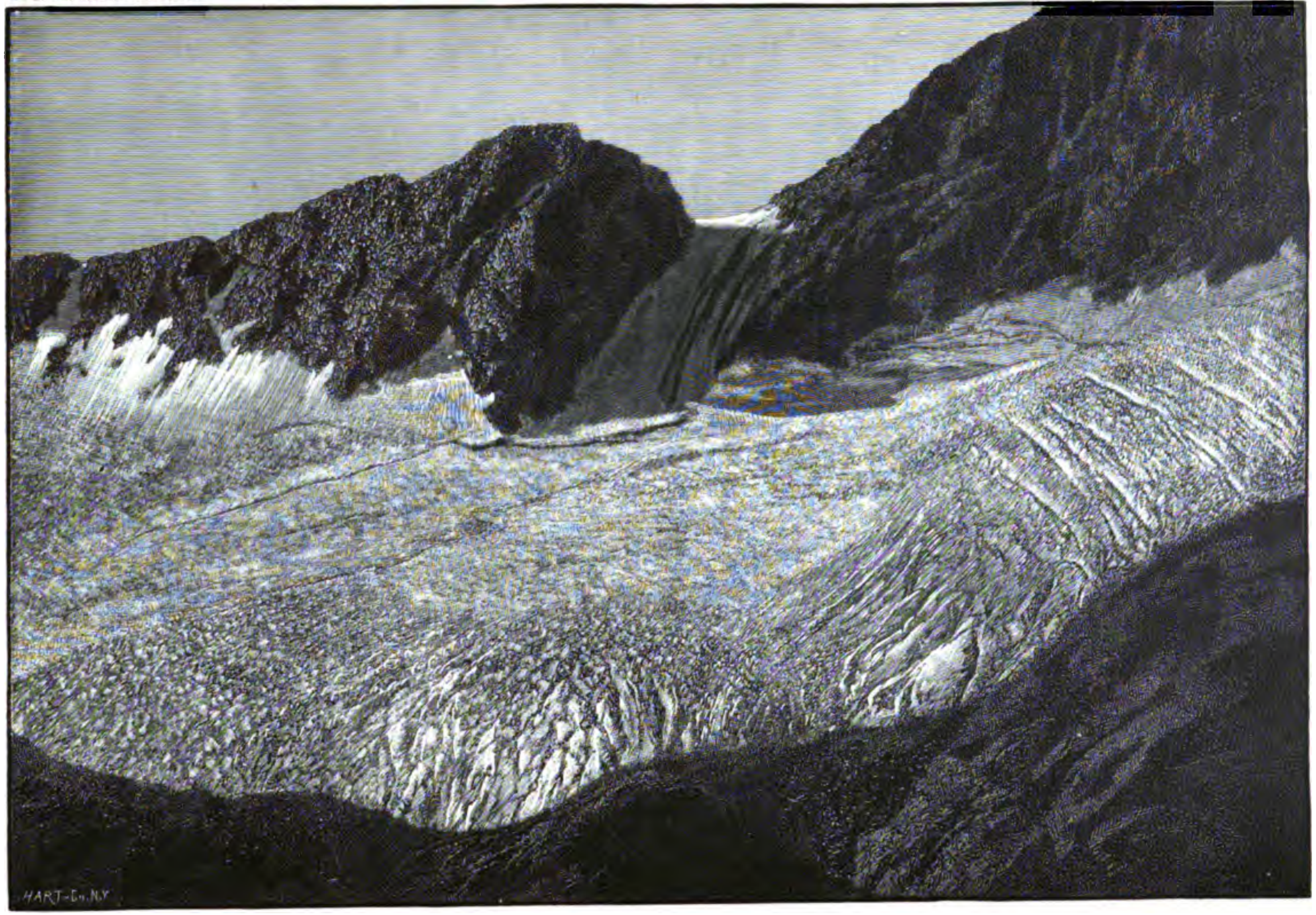

MOUNT DANA GLACIER.

Dirt-bands.—These were observed on nearly all the glaciers, and were frequently a marked and even a conspicuous feature of their surfaces. It required no peculiar condition of light and shade to make them discernible; on the contrary, they could be plainly distinguished at a distance of 2 or 3 miles. Viewed from a distance they were seen to sweep entirely across the glacier in a series of graceful curves concaved towards the *névé*. Sometimes their symmetry was interrupted by irregular undulations, or even by contortions, as may be seen at the foot of the Lyell Glacier. On the Parker Creek Glacier the dirt-bands are about 6 inches broad over a considerable area, and occur at quite regular intervals of from 4 to 6 feet, with comparatively clean ice between. In this instance the dirt producing the bands was not confined to the surface, but could be seen to discolor the ice in quite a well-defined stratum, dipping into the glacier at a low angle. On all the glaciers examined the dirt-bands were observed only below the lower limit of the *névé*.

In the study of the glaciers of Switzerland and Norway particular attention has been given to the influences of ice-cascades in producing laminated structure and dirt-bands. In the Sierra Nevada glaciers, both of these characters are distinct and well marked, but ice-cascades are absent. It seems evident, therefore, that the hypothesis which is apparently satisfactory in Europe will not account for the phenomena to be seen in California.

In viewing many of the Sierra Nevada glaciers from a distance of a few miles, and approximately at the same level, it is apparent that their surfaces, frequently having a slope of from 15° to more than 30°, are in reality sections of the ice-body, and therefore expose its internal structure. When seen in this manner the appearance of the glaciers is such as to lead one to suspect that the dirt-bands are strata in the ice, or in reality "annual rings" formed by annual accumulations of dirt in the *névé*, as long since suggested by Forbes[4] in explanation of the similar bands observed on the Swiss glacier. It is pertinently suggested by Prof. W. H. Brewer that a year of exceptional melting—one of those years which reduce the *névé* to its minimum—would have the effect of combining the dirt accumulated during several years into a single band. A single dirt-band may thus represent a climatic cycle longer than a single year.

Glacier-tables.—Blocks of stone perched on columns of ice, termed "glacier-tables," did not, in 1883, form a marked feature in the glacier surfaces, except in the case of the Parker Creek Glacier. There they were numerous, and in all stages of growth and decadence. Some of the blocks were poised horizontally on their pedestals; others were inclined southward, or had been partially dislodged; again they had fallen and were lying on the southern side of the pinnacles which had formerly supported them. Sketches made on the Parker Creek Glacier of a few of these perched stones have been grouped in the following figure.

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[4] Prof. J. D. Forbes, Travels through the Alps of Savoy, p. 408.

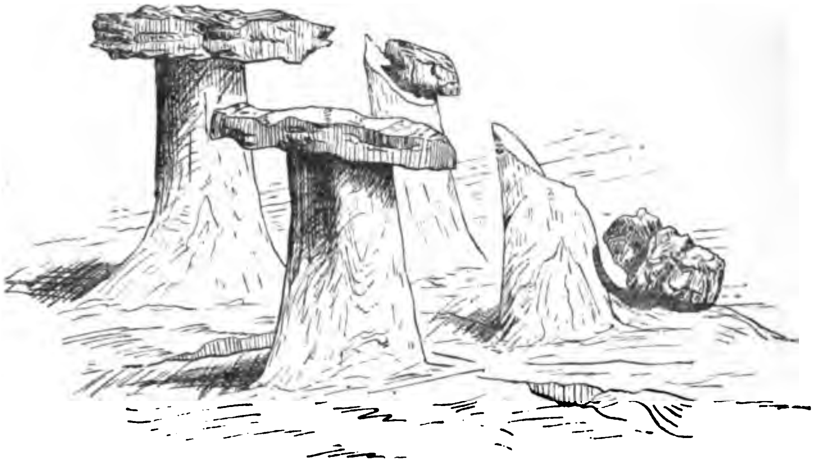

FIG. 138.—Glacier Tables, Parker Creek Glacier.

The largest glacier-table observed was near the center of the Parker Creek Glacier, a few hundred feet from its terminus. This was a block of dense volcanic rock measuring 34 by 23 by 10 feet, supported by a column of ice 8 feet high on its northern and 6 feet high on its southern side, with a thickness of 6 or 8 feet. The smallest blocks that are able to protect the ice beneath sufficiently to form columns as the general surface melts away were found to be about 16 by 10 by 10 inches; when smaller than this they sink into the surface in a manner that has been graphically described by Tyndall and others. Small pebbles were frequently seen at the bottom of little ice-wells 5 or 6 inches deep. Good examples of the "sand-cones" seen so frequently in the Swiss glaciers were not observed.

Ice-pyramids.—As the forms we have included under this name furnish a detail of glacier surface that has not previously attracted our attention and which apparently has not been described by glacialists, we shall transcribe our notes concerning them at some length.

On the lower portion of the Lyell Glacier, more than in any other instance, the surface bristles over a large area with acute pyramids of ice from a few inches to fully 3 feet in height with moderately small bases. At the northern base of each pyramid there invariably is a stone—sometimes measuring 5 or 6 inches in diameter—or a number of loose pebbles or a handful of dirt, which is usually depressed somewhat below the general surface of the glacier. The side of the pyramid rising above the stone, *i. e.*, the northern face, is usually concave and invariably composed of compact ice, while the remainder of the structure

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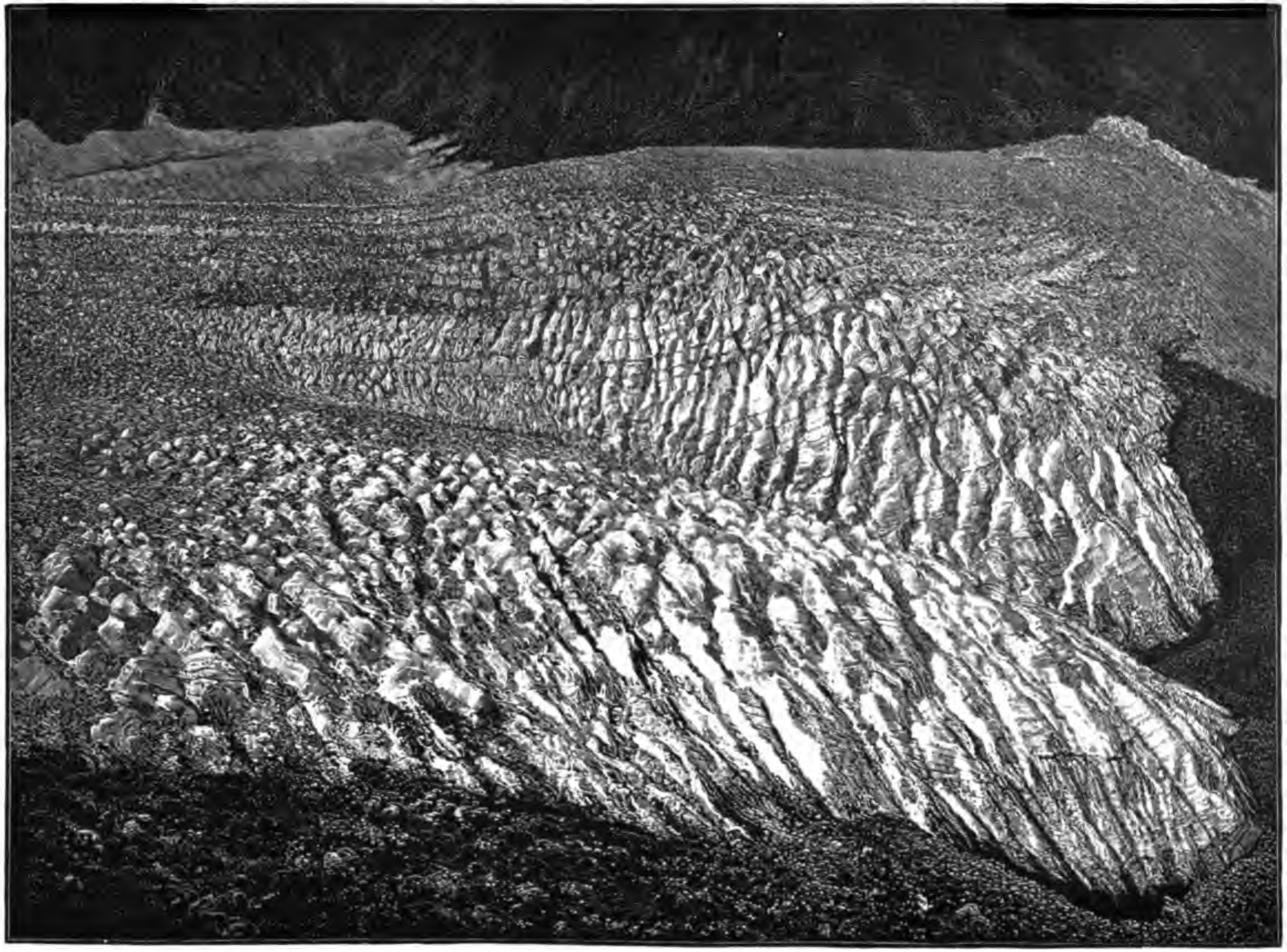

FOOT OF MOUNT DANA GLACIER.

is of the ordinary porous ice forming the glacier surface. Sometimes the nearly horizontal lamination of the glacier-ice can be seen in the southern face of the pyramids. A direct relation is noticeable, too, between the size and shape of the pebble and the height and form of the ice-pyramid that rises above it.

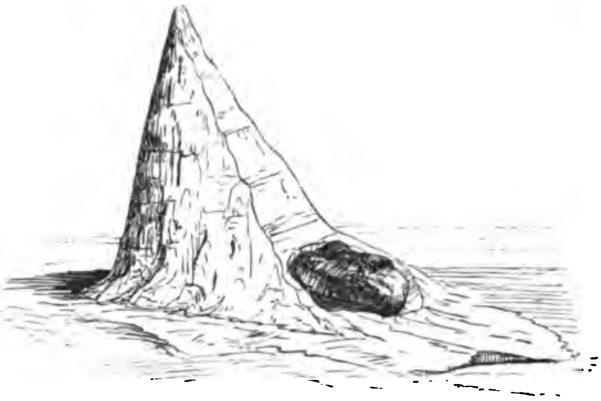

FIG. 139.—Ice-Pyramid on Mount Lyell Glacier.

In seeking an explanation of these phenomena the only hypothesis that seems to satisfy the facts observed assumes that a small stone or mass of dirt lying on the surface of a glacier becomes heated and melts the porous ice beneath, and that the water thus formed freezes again into *compact* ice, which resists the sun's heat more effectually than the surrounding *porous* ice and hence is left as the general surface melts away. In nearly every instance the stone at the base of the pyramid had been carried northward as it melted its way downward, thus forming the steep northern slope of the pyramid, and at the same time tending to prevent the formation of a pyramid on the northern side of a sunken block. The pyramids always point toward the noonday sun, hence the compact ice formed on the northern side of a block is more exposed than that on the southern side, and is therefore more rapidly melted away.

Moraines.—No well-marked medial moraines were noticed on any of the Sierra Nevada glaciers, as they are all simple ice-streams without tributaries. Lateral moraines resting on the ice at the margins of the glaciers were seen in many instances and could be traced to the cliffs from which they originated. Terminal moraines, however, are common; they occur at the lower limit of every glacier observed, and are remarkable for their size when compared with the extent of the parent ice-stream. It is difficult to measure these irregular crescent-shaped heaps with accuracy, owing to the uncertainty of their depth and the manner in which they merge with one another. It is also frequently impossible to determine whether or not they rest on an extension of the glacial ice.

The terminal moraine now forming at the lower extremity of the Dana Glacier is approximately 1,000 feet long by 30 or 40 feet broad and possibly 100 feet deep. Below this, and united with it, is a second of somewhat greater dimensions, which is followed by other similar crescent-shaped heaps of débris. The corresponding moraines at the extremity of the Lyell Glacier are considerably larger, as are also the still more typical terminals at the foot of the Parker Creek Glacier. In some instances these moraines were coated with loose rubbish and dirt that would be swept away by a single storm, indicating that they had received their latest additions within a very few months.

The bottom of the Dana Glacier was seen to be heavily charged with stones, pebbles, and sand, and to rest on a bed of bowlders of considerable thickness. This may be called a "ground moraine."

Glaciated surfaces and scratched stones.—The rock surfaces in the immediate neighborhood of the glaciers are frequently polished and covered with a net-work of grooves and scratches, but it is usually impossible to determine whether this has been the work of the existing ice-streams or whether it is a part of the vast glaciation imposed upon all of the High Sierra during the Glacial epoch. In some instances, however, there is no doubt that the markings were made during the past few years.

At the immediate foot of the Dana Glacier we found a number of stones that were battered and worn and exhibited planed and scratched surfaces, in many respects similar to the glaciated stones found in the ancient moraines of New England. These occurred but a few feet from the ice-foot, and their bruises and scratches were, without question, the work of the present glacier.

Glacier movements.—Measurement of the motions of the glaciers was not undertaken, but their movement is apparent both from the nature of the crevasses and the curved course of the dirt-bands that cross them. The rate of the flow of a glacier on Mount McClure, however, was determined more than ten years since by Mr. John Muir, who found its maximum movement near the center to be 47 inches in forty-six days (from August 21 to October 6, 1872).[5]

Glacier mud.—The Tuolumne River has its source at the foot of the Lyell Glacier; at its birth it is a rivulet, turbid with silt that has been ground fine by the moving ice from beneath which it issues. At the foot of the Dana Glacier there is a small lakelet confined in a rock-basin, which acquires a peculiar greenish-yellow color from the silt held in suspension. The water escapes from this lake through an ancient moraine piled on the rim of the basin, and is gathered in other depressions farther down the cañon, forming lakelets that are wonderfully clear and blue, like the hundreds of sister lakes scattered throughout the surrounding glaciated area. The sediment from the glacial streams

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[5] Postea, p. 324.

T LYELL FROM THE TUOLUMNE VALLEY.

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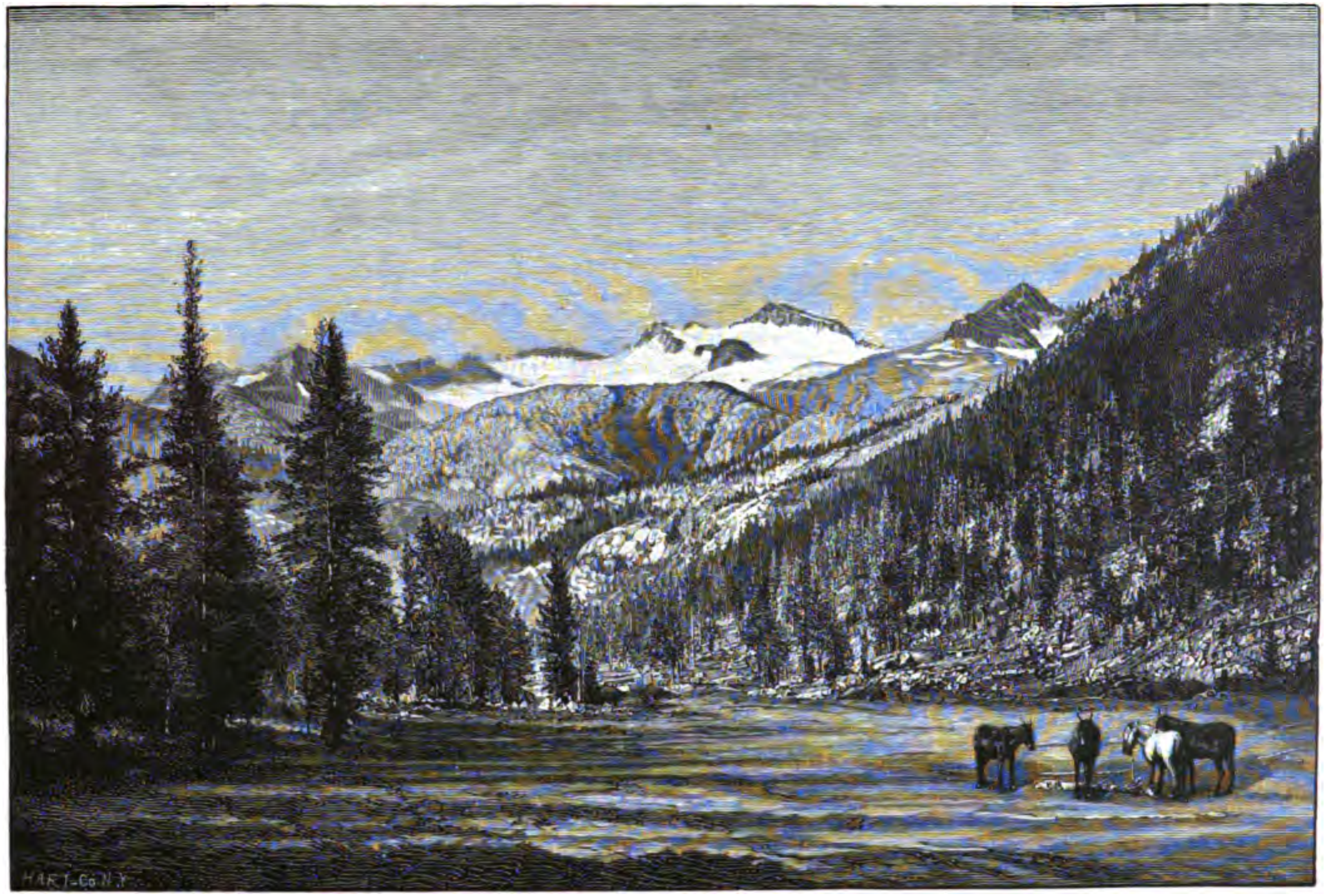

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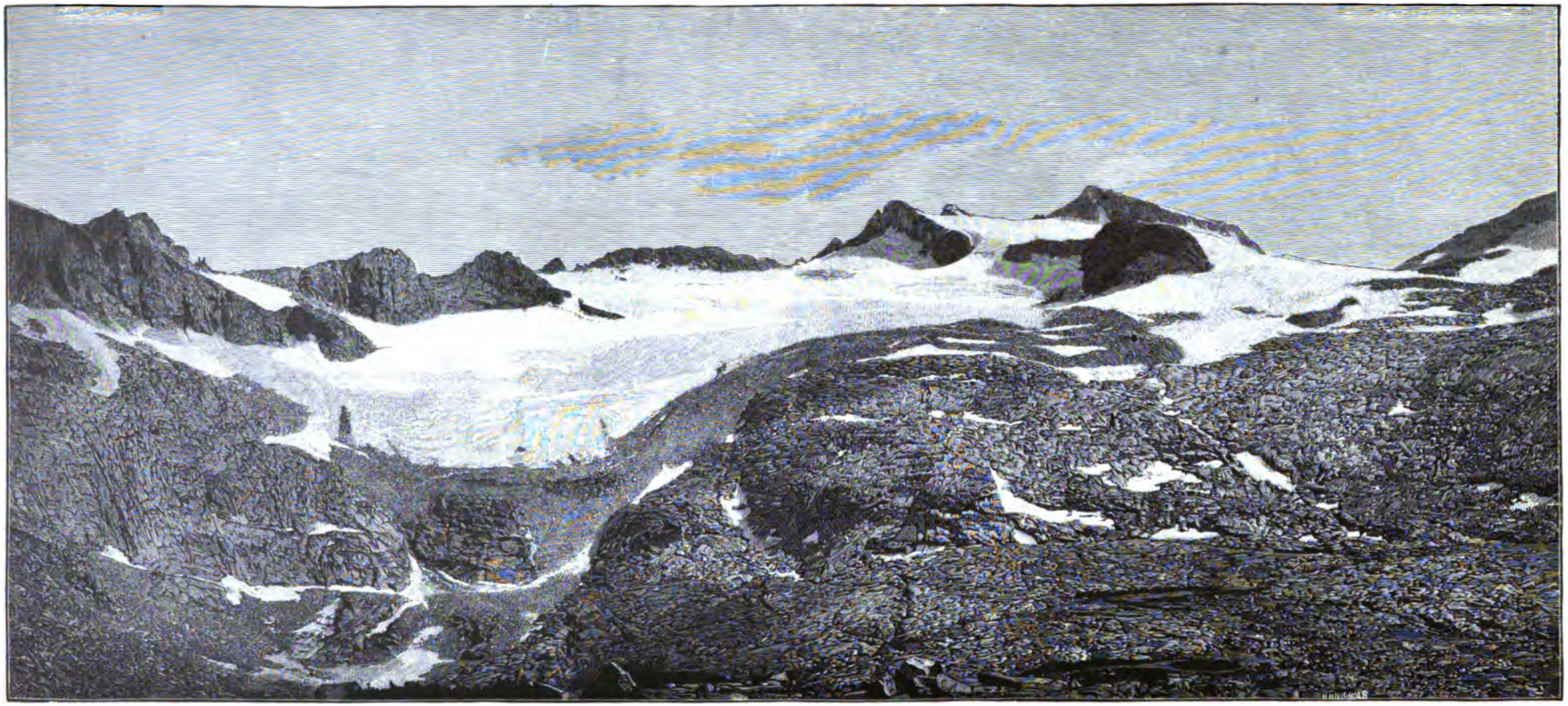

MOUNT LYELL GLACIER.

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Ice tongues.—In the steep amphithe[illegible] the glaciers there are frequently seen [illegible] the higher peaks. In many instances these a[illegible] which shoots up above the *névé* in tape[illegible] feet in height and at so high an angle that [illegible] or descend them without cutting steps. These [illegible] teresting feature of the Sierra glaciers, and ap[illegible] the ice streams of Wyoming; whether they have [illegible] remains to be determined.

Red snow.—While Mr. Gilbert and myself were ex[illegible] portion of the Lyell Glacier, we no[illegible] that our foot pr[illegible] had a bright pink tint [illegible] surface appear[illegible] gravish white. At the lower [illegible] of the *névé* the color more distinct and could be plainly [illegible] the untrodden [illegible] in some instances the borders of rills were [illegible] stained. [illegible] the "red snow" was superficial. Some of [illegible] coloring matter [illegible] was examined with a microscope a number of [illegible] and [illegible] to [illegible] globules from 150 to 200 [illegible] which were determined to be the [illegible]

The melting of the glaciers.—Our [illegible] began one August morning [illegible] which the ice is crested was [illegible] to mountain-top. As the sun rose above the [illegible] eastward and flushed the snow fields with [illegible] ruddy [illegible] started here and there on the glacier, gradually gathering [illegible] as the sun's warmth increased. By noon brooks of considerable [illegible] rushing down channels of ice, sometimes plunging into crev[illegible] becoming lost to view. At midday the murmur of water [illegible] everywhere over the glacier, but as the [illegible] of the streams gradually cease[illegible] death again [illegible] over the frozen reg[illegible]

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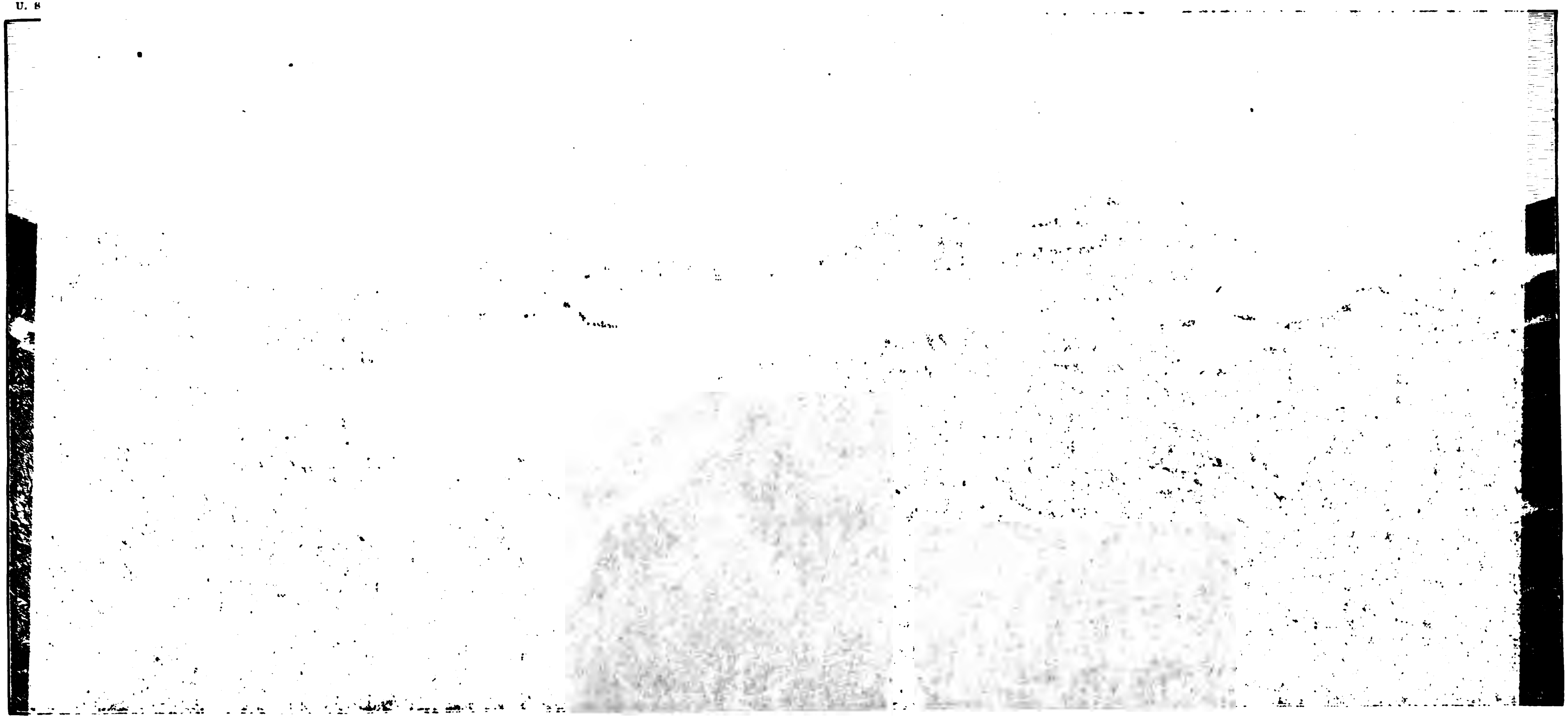
[1] [illegible] J. D. Whitney [illegible] an account of [illegible] Mount [illegible] [illegible] Vol. I, p. 388 [illegible] the occurrence [illegible] an elevation of from [illegible] to 12,000 [illegible] *Protococcus nivalis*.

[2] Poss[illegible], pp. 3[illegible]



MOUNT LYELL GLACIER.

was found to be an impalpable mud, so extremely fine that it requirde a long time to settle when once diffused through water.

Ice-tongues.—In the steep amphitheater walls overlooking the ***névés*** of the glaciers there are frequently deep, narrow cliffs leading towards the higher peaks. In many instances these are partially filled with ice, which shoots up above the ***névés*** in tapering tongues some hundreds of feet in height, and at so high an angle that it is impossible to ascend or descend them without cutting steps. These "ice-tongues" are an interesting feature of the Sierra glaciers, and appear also at the head of the ice-streams of Wyoming; whether they have glacial motion or not remains to be determined.

Red snow.—While Mr. Gilbert and myself were examining the ***névé*** portion of the Lyell Glacier, we noticed that our foot-prints in the snow had a bright pinkish tint, the undisturbed surface appearing white or, perhaps, grayish white. At the lower border of the ***névé*** the color becomes more distinct and could be plainly seen in the untrodden surface, and in some instances the borders of rills were brightly stained. In all cases the "red snow" was superficial. Some of the coloring matter collected was examined with a microscope a number of months after and found to consist of deep red globules from 150 to 200 millimeters in diameter, which were determined to be the still form of *Protococcus*.[6]

The melting of the glaciers.—Our examination of the Lyell Glacier began one August morning before sunrise, when the vast amphitheater in which the ice is cradled was hushed in the profound stillness peculiar to mountain-tops. As the sun rose above the granite spires to the eastward and flushed the snow-fields with a ruddy light, little rills started here and there on the glacier, gradually gathering strength as the sun's warmth increased. By noon brooks of considerable size were rushing down channels of ice, sometimes plunging into crevasses and becoming lost to view. At midday the murmur of water was heard everywhere over the glacier, but as the chill of evening came on, the music of the streams gradually ceased, and by sunset the stillness of death again reigned over the frozen regions.

That this noonday melting has more than counterbalanced the annual additions which the glacier has received during the past few years, seems evident from the accounts we have of the previous extent of the snow-fields of the High Sierra.[7] The glaciers of California, like those of Switzerland, are probably subject to periodic changes due to climatic oscillations, and are evidently not increasing at the present time.

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[6] Prof. J. D. Whitney, in an account of an ascent of Mount Shasta—Geology of California, Vol. I, p. 338—mentions the occurrence of "red snow" over a very considerable area at an elevation of from 8,000 to 12,000 feet, and ascribes its color to the presence of *Protococcus nivalis*.

[7] Postea, pp. 324–326.

PREVIOUS EXPLORATIONS.

Although giving precedence to my own observations in describing the glaciers of the High Sierra, I do not wish to ignore the reports of those who have preceded me. The anonymous article on the "Living Glaciers of California"[8] which appeared in the Overland Monthly for December, 1872, we have already referred to as being from the pen of Mr. John Muir, and is, so far as known, the first announcement of the existence of glaciers in the Sierra Nevada. Mr. Muir states that in October, 1871, he was among the mountains of the "Merced group" and found a living glacier, with very recent moraines at its foot, from beneath which issued a stream charged with fine mud; further observation revealed dirt-bands, crevasses, and lateral moraines, thus leaving no doubt that the "snow-bank," as it had previously been considered, was an actual glacier. Other similar ice-bodies were examined by Mr. Muir on Mount Lyell and Mount McClure; and from the top of Mount Lyell he saw a dozen small glaciers on neighboring peaks.

In August, 1872, Mr. Muir placed five stakes in the glacier on Mount McClure for the purpose of demonstrating that it had true "glacial motion." Four of these were ranged in line from the east side to a point near the middle of the glacier, the first being 25 yards from the east bank; the second, 94; the third, 152; and the fourth, 225 yards. On observing the stakes on October 6, forty-six days after being placed in position, it was found that No. 1 had been carried down the glacier 11 inches; No. 2, 18 inches; No. 3, 34 inches; No. 4, 47 inches. Stake No. 4 was near the middle of the glacier and was thought to represent the maximum motion. Stake No. 5 was placed about midway between the head of the glacier and stake No. 4; its motion was 40 inches in 46 days. These measurements, although not as detailed and perhaps not as accurate as could be desired, are yet sufficient to demonstrate, as claimed by Mr. Muir, that the ice in this instance has true glacial motion. In this example, as in all normal glaciers, the most rapid movement was near the middle of the ice-stream.[9]

The Mount McClure Glacier, when visited by Mr. Muir, was approximately half a mile long, and of about the same breadth in the widest part, and was observed to be traversed in the southeast corner by crevasses several hundred yards long but only about a foot wide. The Mount Lyell Glacier, in 1872, is stated to have been about a mile in length by a mile in breadth.

Mr. Muir also describes narrow high-grade cañons called "devil's slide," "devil's lanes," etc., which occur about the higher peaks and are frequently occupied by ice. In one of these gorges the ice was found

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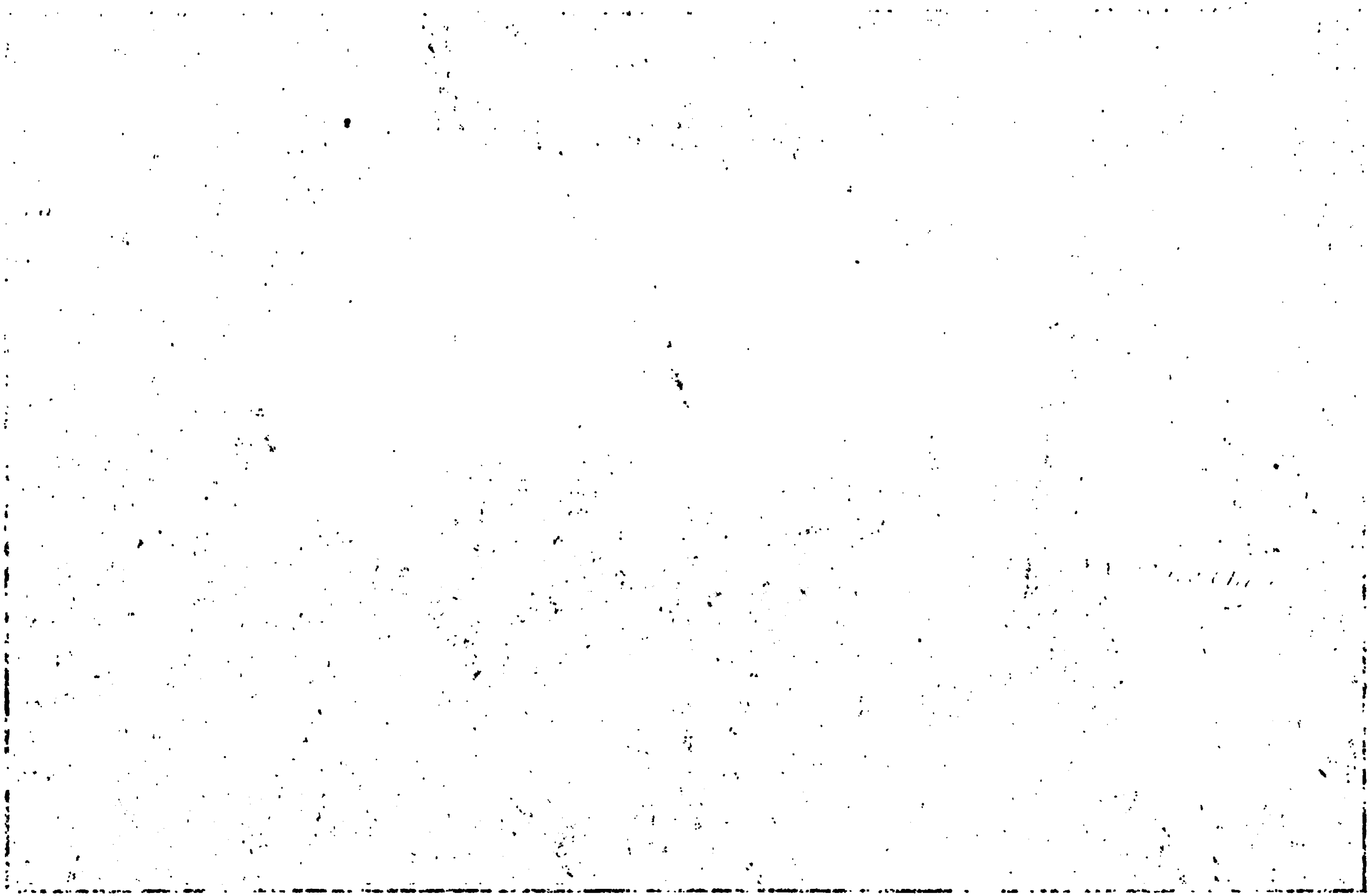
[8] Reprinted in the American Journal of Science, Vol. V, Third series, 1873, p. 69.

[9] Motion in the Lyell Glacier is also referred to by Salem Clarke. Proceedings of the Boston Society of Nat. Hist., Vol. XV, 1873, p. 259.



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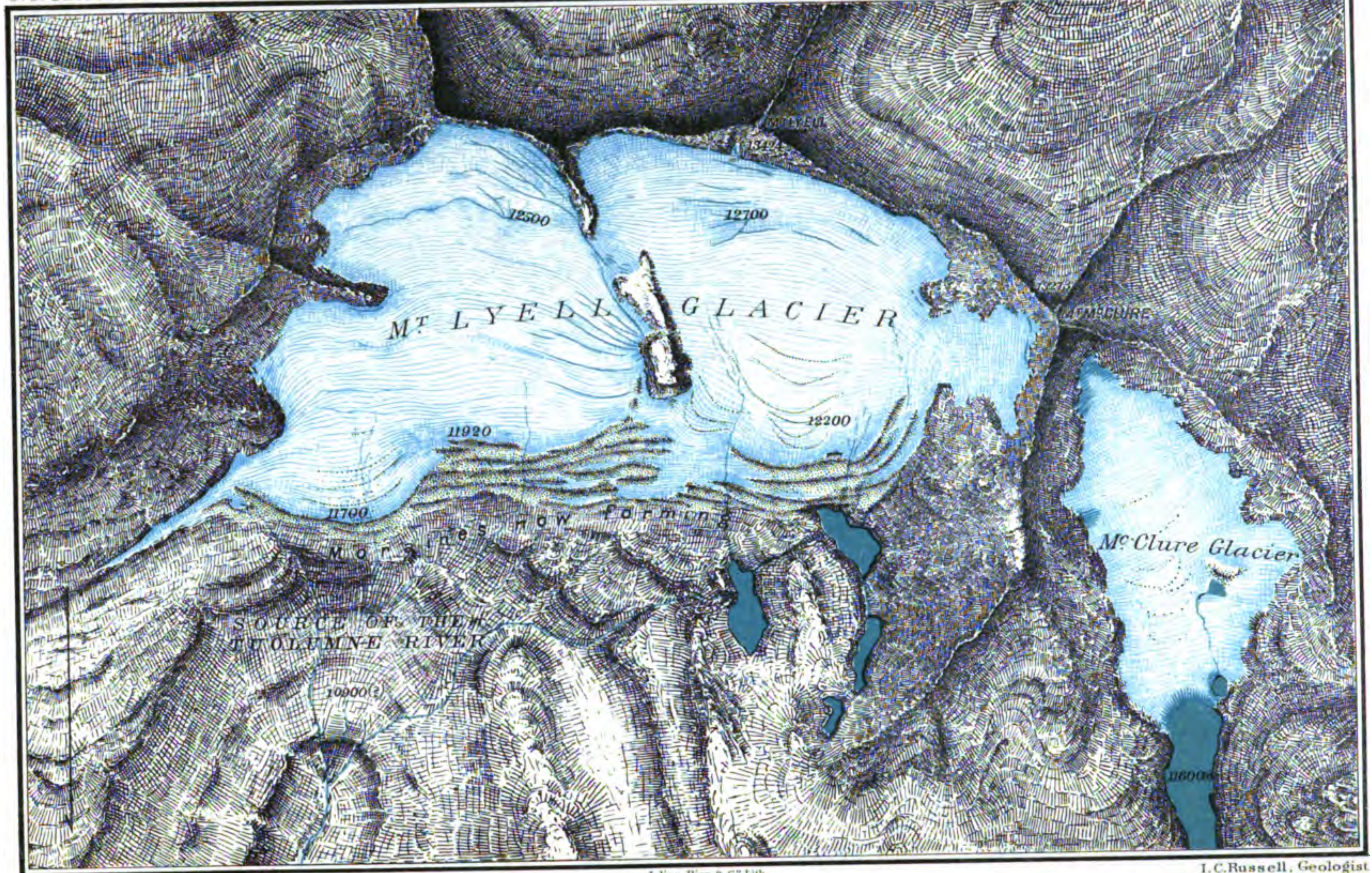
U. S. GEOLOGICAL SURVEY FIFTH ANNUAL REPORT PL. XL



W. D. Johnson, Topographer.

Julius Bien & Co Lith.

I. C. Russell, Geologist.

Mt LYELL GLACIER.

Scale: 3¼ inches - 1 mile.

to have a motion of a fraction of an inch per day. It is probable that these small ice-bodies are what we have called "ice-tongues" in describing our observations of last summer. In an article entitled "In the heart of the California Alps,"[10] Mr. Muir gives some account of the glaciers about Mount Ritter, combined with enthusiastic descriptions of the magnificent scenery of the Sierra. In another article from the same pen, "Living Glaciers of California," published in Harper's Magazine,[11] a number of illustrations of glacial scenery are introduced, together with popular descriptions of numerous *névés* and ice-fields.

Prof. Joseph Le Conte visited the High Sierra during the summers of 1872 and 1873, and in company with Mr. Muir examined the summit of Mount Lyell.[12] While describing the records of the ancient glacier that once filled the Tuolumne Valley, Professor Le Conte says,[13] that what interested him far more than anything else seen during his journey "was that the main branch of the Tuolumne Glacier, far up among the cliffs and peaks of Mount Lyell, *still exists as a living glacier*, in feeble state of activity it is true, but certainly living." Professor Le Conte accepts Mr. Muir's measurement, and concludes that "*the glacier motion still exists.*"

That the Lyell Glacier was more completely hidden by snow when examined by LeConte in 1872, than ten years later when seen by the writer, appears from the following paragraph, from the American Journal of Science:

"Here, then, on Mount Lyell we have *now existing*, *not a true glacier*, perhaps, certainly *not a typical glacier* (since there is no true glacier-ice visible, but only snow and *névé*; and certainly *no protrusion of an ice-tongue beyond the snow field*), yet nevertheless *in some sense a glacier*, since there is true differential motion and a well-marked terminal moraine. It is in fact a glacier in feeble old age, a feeble remnant of the Tuolumne Glacier, a glacier once of great proportions and playing an important part in mountain sculpture but now in its second childhood."

Le Conte found the surface of the snow on the *névé* of the Lyell Glacier "traversed in a direction at right angles to the slope by *sharp blades* of half compacted ice about 2 feet apart and 2, 3, 4, or even 5 feet in height; * * * the crests of the blades were not continuous, but irregular both in outline and trend, very much in this respect like ripple marks or like waves."[14] The explanation offered—suggested by Mr. T. C. Gardner—is that the blades are due to the action of the sun or wind ripples forming on the surface of the *névé*.

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[10] Scribner's Monthly, Vol. XX, 1880, p. 345.

[11] Vol. LI, 1875, p. 769.

[12] A portion of the results of these journeys was published in a paper, "On some of the ancient glaciers of the Sierra," Proceedings of the California Academy of Sciences, Vol. IV, 1872, p. 159; and also, in a more extended form, in the American Journal of Science, Third series, Vol. V, 1873, p. 325. See also Le Conte's Elements of Geology, Revised Edition, 1882, p. 602.

[13] Page 332.

[14] American Journal of Science, Third series, Vol. V, 1873, p. 332.

In the publications of the Geological Survey of California no mention is made of existing glaciers in the Sierra Nevada. The frontispiece of Volume I (Geology), showing Mount Lyell from the head of the Tuolumne, and also a sketch of the summit of the peak, forming Fig. 73, indicate that the mountains were then far more heavily mantled with snow than when visited by the writer in 1882 and 1883. Prof. J. D. Whitney, in his work on "Climatic Changes of Later Geological Time,"[15] says, "It may be stated there are no glaciers at all in the Sierra Nevada proper, and none in the Great Basin or Rocky Mountain ranges, at least south of the parallel of 42°. With the exception of some recent discoveries said to have been made in 1878 in the Wind River Range (about Latitude 43°) by the U. S. Geological Surveying party, of which no definite account seems as yet to have been published, it may be stated that there are no proper glaciers anywhere within the limits of the United States (Alaska not included), except around the great isolated volcanic cones of the Pacific coast. There are certainly none in the higher portions of the Sierra Nevada or the Rocky Mountains, these most elevated regions having been sufficiently explored to ascertain that fact." It will be noticed that this passage was published in 1882, or ten years later than Muir's and Le Conte's observations cited above. On page 30 of Professor Whitney's work the notes of Messrs. King and Gardner, made in 1868 while exploring the eastern slope of Mount Ritter, are transcribed as follows: "In a deep *cul-de-sac* which opens southward on the east slope (of Mount Ritter) lies a bed of ice 200 yards wide, and about half a mile long. It has moved down from the upper end of the gorge for 30 or 40 feet this year, leaving a deep gulf between the vertical stone wall and the ice." In connection with the observations Professor Whitney remarks that "it is doubtful whether these residual masses of ice can with propriety be called glaciers."

Mr. King also rejected Mr. Muir's observations, as is shown by several emphatic passages in his report of the Exploration of the 40th Parallel,[16] but adds no new information on the subject.

From the quotations that have been given it will be seen that the question of the existence of glaciers in the Sierra Nevada has been decided differently by different observers, who perhaps saw the mountains under diverse conditions as regards their snowy covering. In winter the glaciers are buried so deeply beneath accumulations of snow that no one would suspect their existence; it is only late in summer, when the snows have decreased to a minimum, that they are to be seen to the greatest advantage. That Mr. Muir was correct in classing many of the snow masses as glaciers is sustained by recent investigation, but the observations on which he based his determinations seem not to have been sufficient to convince all observers who visited them when the mountains were more completely snow-clad than at present.

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[15] Memoirs of the Museum of Comparative Zoölogy of Harvard College, Vol. VII, 1882, No. 2, p. 25.

[16] Vol. I, pp. 447, 478.

[illegible] the Geological Survey of California no men- [illegible] glaciers in the Sierra Nevada. The frontis- [illegible] showing Mount Lyell from the head of the [illegible] sketch of the summit of the peak, forming Fig. 73, [illegible] were [illegible] far more heavily mantled with [illegible] 188[illegible]. Prof. J. D. Whit- [illegible] Later Geological [illegible] [illegible] glaciers at all in the Sierra Nevada [illegible] Rocky Mountain ranges, at least [illegible] the exception of some recent dis- [illegible] on the Wind River Range [illegible] U. S. G[illegible] Surveying party, of which [illegible] published, it may be [illegible] where [illegible] than the limits of [illegible], except around the great iso- [illegible] coast. Th[illegible] certainly none in [illegible] Rocky Mountains, these [illegible] explored to ascertain [illegible] was published in 1882, [illegible] observations cited above, [illegible] notes of Messrs. King and [illegible] slope of Mount [illegible] deep *cul de sac* which opens [illegible] lies a bed of ice 200 yards [illegible] moved down from the upper [illegible] leaving a deep gulf between [illegible] connection with the observations [illegible] whether these residual [illegible] glaciers."

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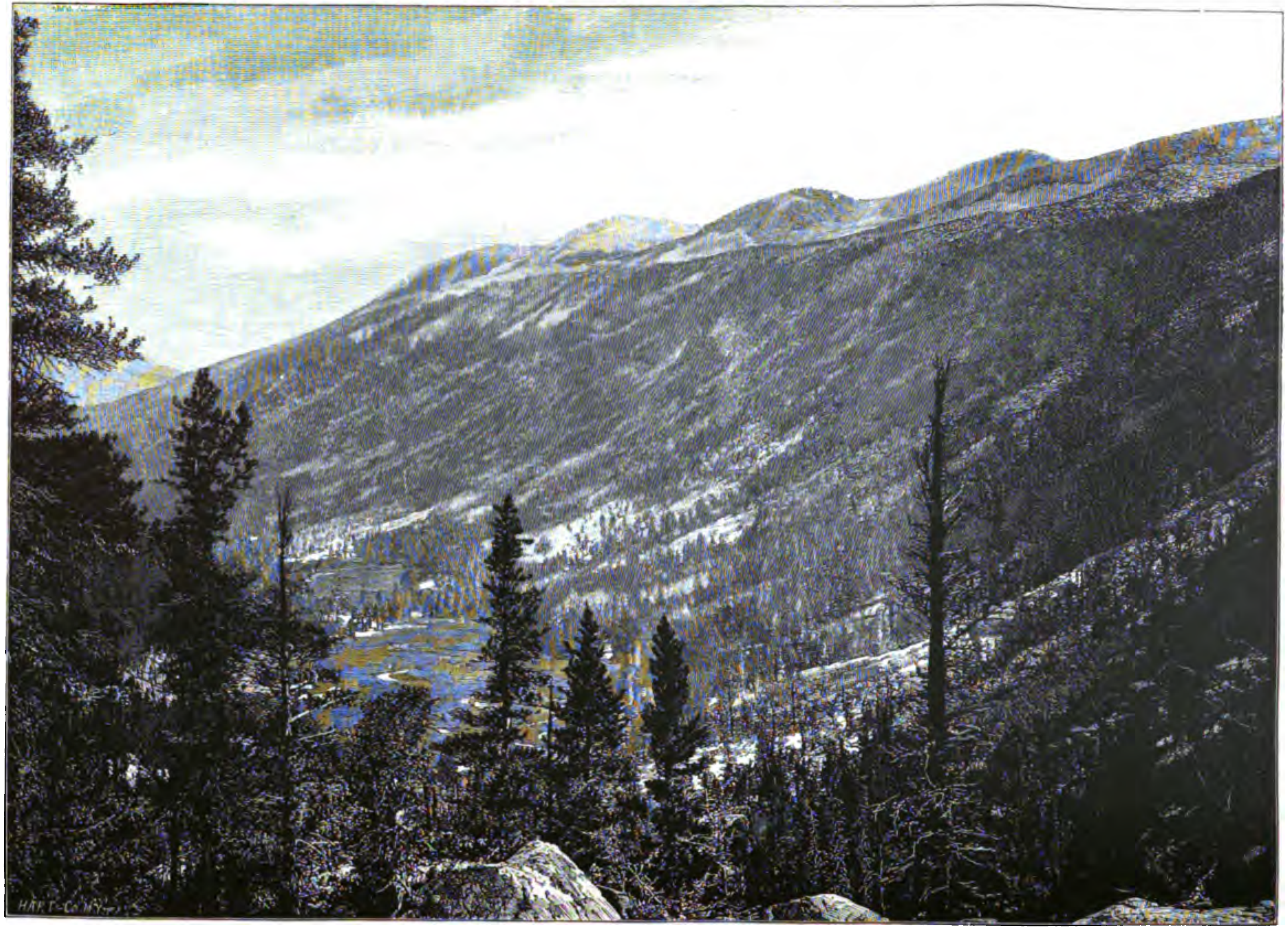


VIEW DOWN THE TUOLUMNE VALLEY FROM MOUNT LYELL

ANCIENT GLACIERS OF THE SIERRA NEVADA.

In the present essay it was intended to confine attention to living glaciers, but the subject is so intimately connected with the records of the ancient ice-streams which flowed from the same amphitheater that a few words in reference to the former glaciation of the Sierra Nevada, principally in explanation of the topography shown on Plate XXXII, may not be out of place.

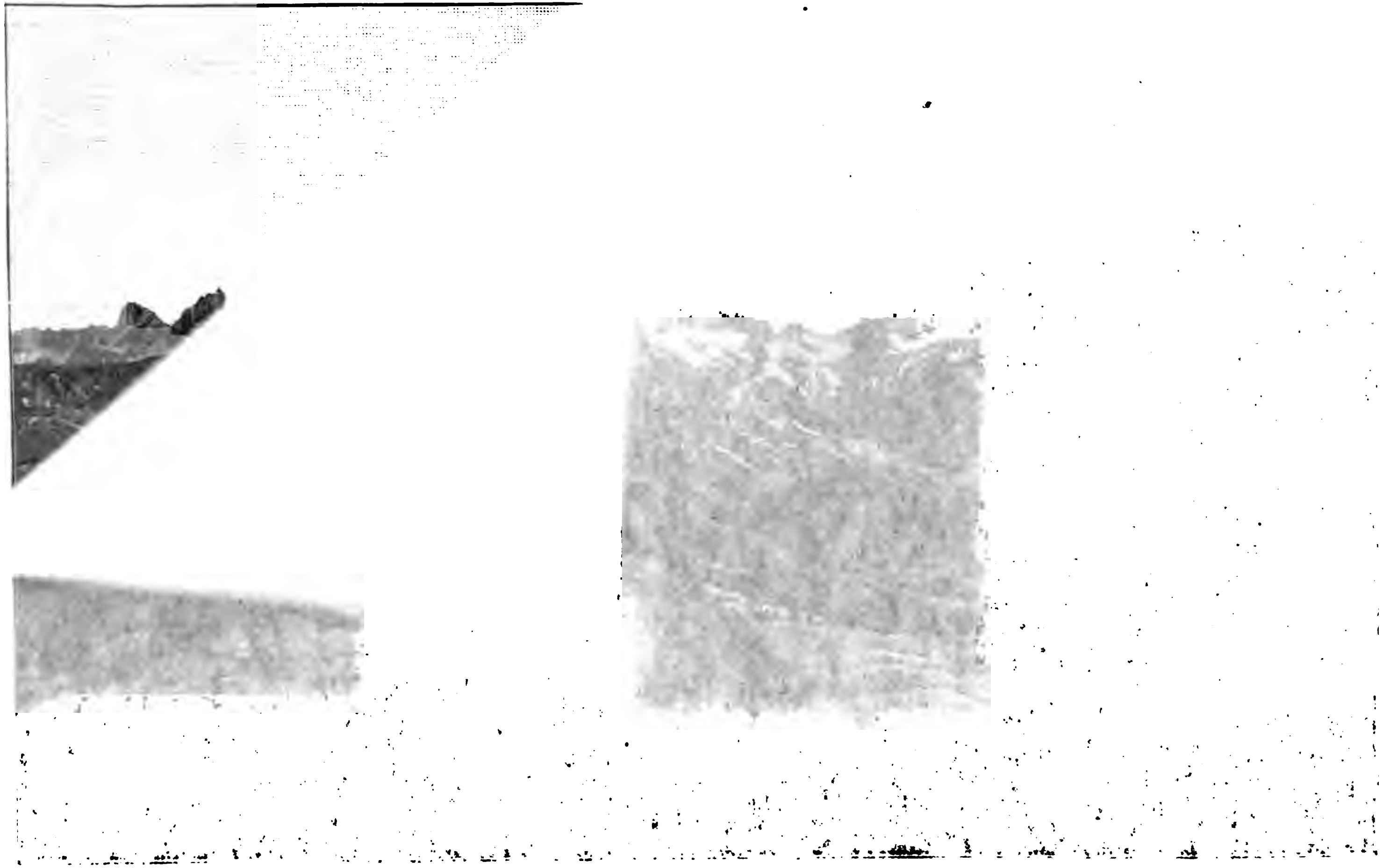
Exploration has now been carried far enough to show that nearly all the higher portion of the Sierra Nevada, excepting the very highest peaks and crests, were at no distant date, geologically speaking, loaded with an immense accumulation of snow and ice, forming a vast *névé* from beneath which trunk glaciers flowed down the cañons both eastward and westward from the crest of the range. The ice-streams that went westward were longer and far larger than those which descended the eastern escarpment, for the reason that the western slope is much less precipitous than the eastern, thus affording larger *névés* and necessitating a longer journey before the ice could reach an horizon sufficiently warm to cause it to melt. Precipitation during the Glacial epoch, as at present, was probably most abundant on the western slope of the range, thus assuring abundant supplies for the mighty ice-rivers.

In that portion of the High Sierra to the westward of Mono Lake, which is shown on Plate XXXII, the more pronounced topographical features resulting from the ancient glaciation are conspicuously displayed. The broad-bottomed valley leading northward from Mount Lyell was formerly occupied by the great Tuolumne glacier. This received an important tributary from the region westward of Mount Dana, the path of which is deeply engraved in the topography of the country. The glacier formed by the union of these two ice-streams flowed down the Tuolumne Cañon for 30 or 40 miles, with a depth of between 2,000 and 3,000 feet, and it is believed to have occupied the Hetch-Hetchy Valley, but its full extent is not known. Other magnificent glaciers having their sources about Mount Lyell and Mount Ritter descended the Merced and San Joaquin valleys, which, like the Tuolumne, were considerably modified by ice-erosion. To the eastward of the divide between the drainage to the Pacific and the Great Basin, as indicated on Plate XXXII, the paths of the ancient glaciers are definitely recorded by the smoothed and rounded character of the valleys they occupied. Their channels are frequently fringed with lateral moraines, which in some instances were carried beyond the mouths of the cañons and prolonged upon the plain as parallel embankments. This feature is especially illustrated by the moraines at the mouths of Bloody, Parker, and Rash Creek cañons. At Bloody Cañon and Parker Creek two separate extensions of the glaciers are recorded by the morainal embankments. The glacier that flowed down Bloody Cañon advanced upon the plain with a slight deflection to the right, and built out a pair of morainal embankments, as indicated on the map; subsequently the ice retreated at least as far as the mouth of the cañon, and then advanced a second time with a deflection to the left, *i. e.*, northward, and formed a pair of parallel embankments larger than the first. Two similar advances of the Parker Creek glacier are also recorded by the very perfect moraines still remaining. The ice-stream which formerly occupied the valley of Rash Creek was by far the largest that entered the Mono Basin, and has many features of interest, which, owing to their diversity and complexity, cannot be fully described at the present time. As shown by the topography and the well-preserved moraines, this glacier was over 1,500 feet thick where it left the cañon; before reaching the plain it was divided by a high rocky spur into two branches, thus producing the peculiar horseshoe-shaped cañon shown on the map. The more southern branch deposited terminal moraines in such a way as to obstruct the outlet of the valley and cause a reversal of the stream when the glacier melted.

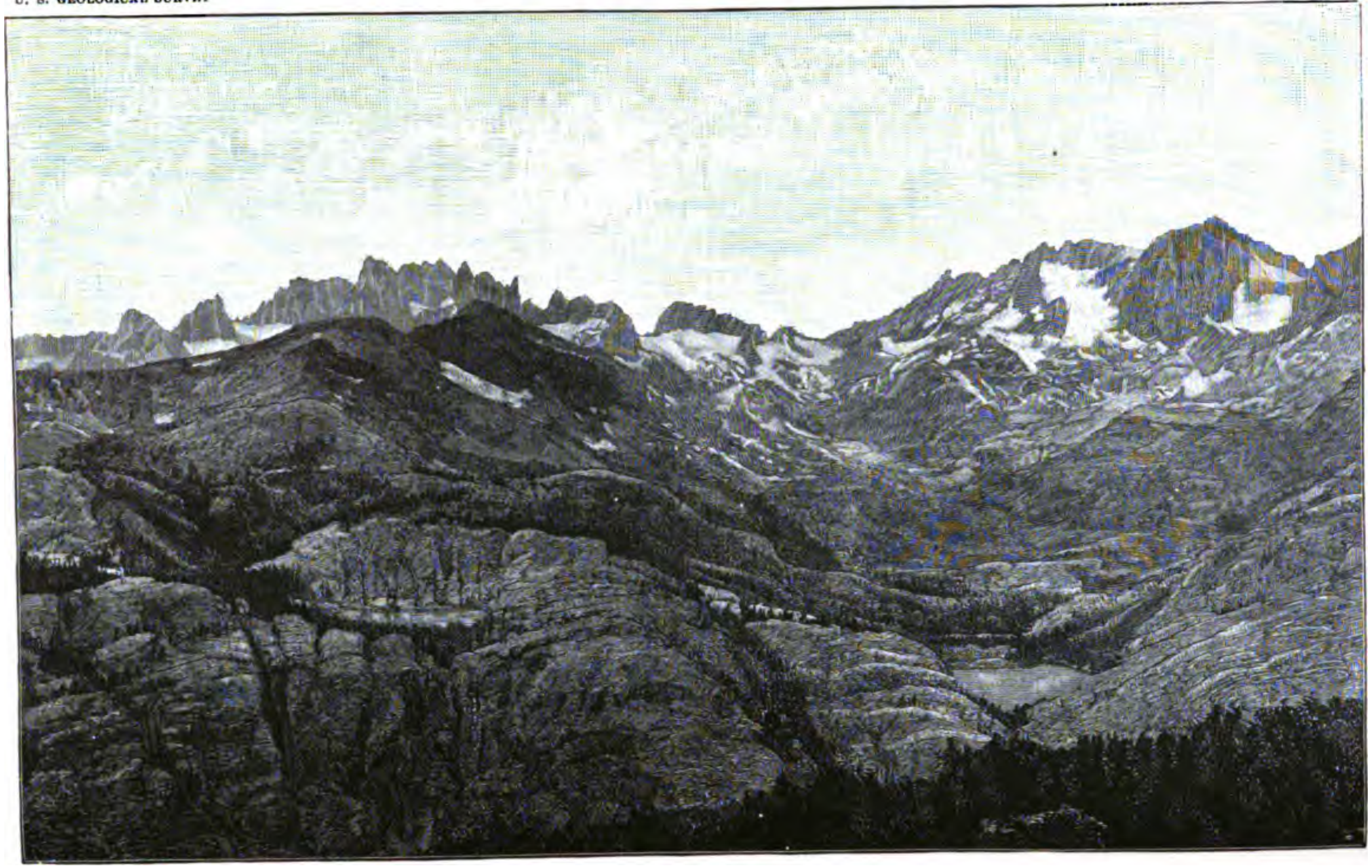
The ancient glaciers of the region embraced in the map are shown approximately on the transparent over-plate accompanying it. The general *névé* region is there indicated by light blue and the more important ice-streams by a darker shade. The glaciation of the *névé* region, embracing nearly all the higher portions of the range, merges so gradually into the records made by the well-defined glaciers which flowed from it that it is frequently impossible to determine the upper limits of the trunk glaciers; their lower courses, however, are usually well defined by lateral and terminal moraines.

The contrast between the existing and extinct glaciers of this region is strikingly illustrated by the map and over-plate, which show that the present glaciers occur at the heads of valleys and cañons that were formerly the channels of magnificent ice-rivers. Could the climatic conditions favorable to the growth of glaciers be reinstated, we should see the present insignificant ice-bodies gradually increase until the ancient channels were again flooded and all the higher portions of the High Sierra buried beneath a vast *mer de glace.*

Many features in the glaciation of the High Sierra will receive further attention in connection with the study of the Quaternary history of the Mono Basin, which is now in progress.



THE [illegible], FROM THE EAST.



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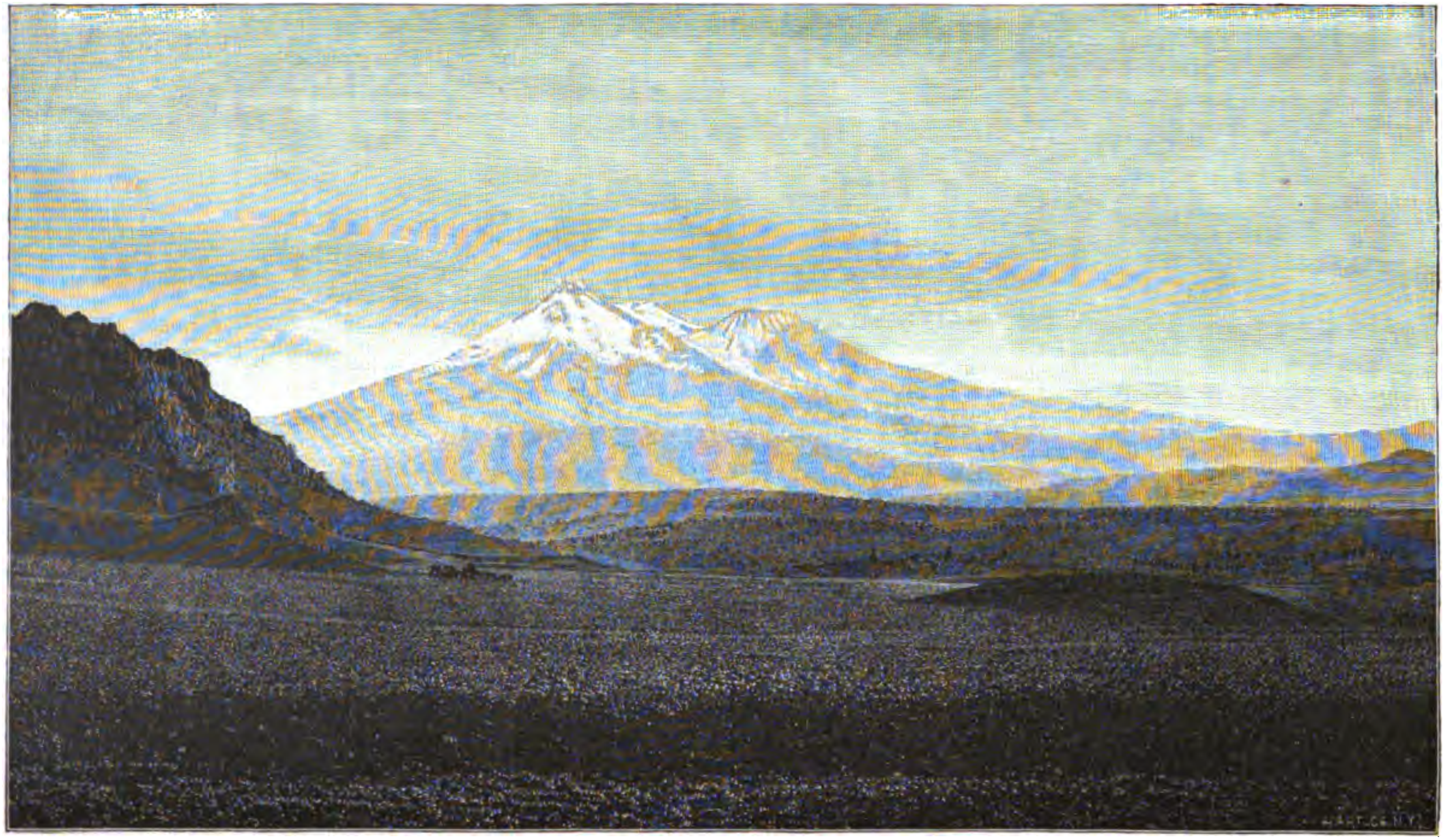

MOUNT SHASTA, CALIFORNIA.

GLACIERS OF NORTHERN [illegible]
CA[illegible]

The Sierra Nevada [illegible] near the northern bo[illegible] the limit of the di[illegible] terminated. The [illegible] northern California [illegible] ical feature through Oregon [illegible] North of California the [illegible] Mountains, and, unlike the [illegible] is generally cons[illegible] and form the [illegible] is more thorough[illegible] in the same range [illegible] cones, the glory of the [illegible] pleted, yet enough is kn[illegible] glacier crowned. Beginning at the south[illegible] observations as have been reported concerning [illegible]

MOUNT SHASTA.

The earliest account of the glaciers of Mount Shasta [illegible] Clarence King,[7] who ascended the peak in Septe[illegible] panied by several members of the United States Geolog[illegible] tion of the 40th Parallel. We transcribe entire the portion [illegible] which relates directly to the glaciers:

"On September the 11th we climbed to the [illegible] a conical secondary crater jutting out from the [illegible] ain on its northwest side. * * * We [illegible] and looked down into a deep gorge lying [illegible] and the main mass of Shasta, and saw direct[illegible] which started almost at the very crest of t[illegible] towards us, and curving around the circular ba[illegible] tire length in view was not less than 3 miles, [illegible] station about [illegible] feet, the surface here and there [illegible] "cascades," and presenting all the characteristic f[illegible] glaciers elsewhere. The region of the terminal mor[illegible] tended than is usual in the Alps. The [illegible]

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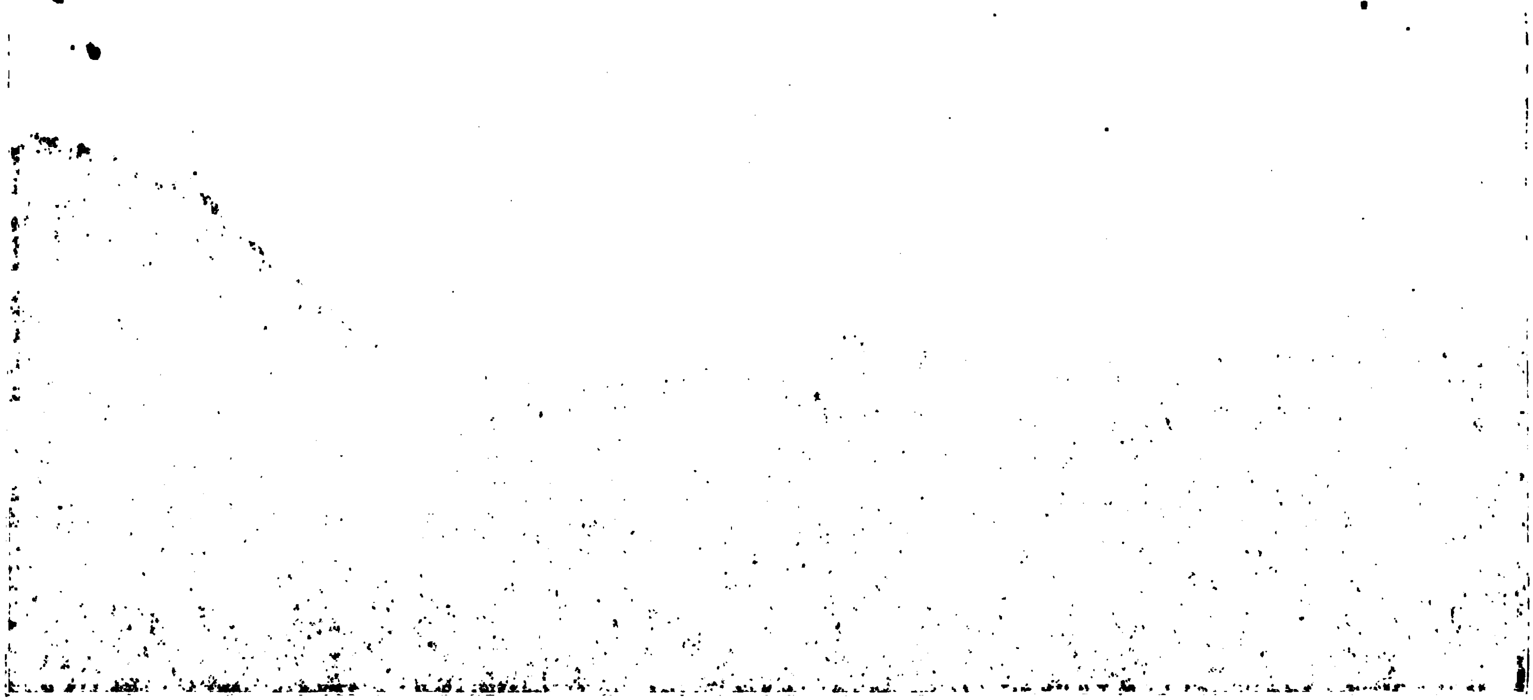
[7] American Jo[illegible] V[illegible] I. Third series, 1871, p[illegible] was published in "Mountaineering in the Sierra Nevada[illegible]

[illegible] Shastina on the accompanying [illegible] Plate [illegible]

[illegible] is now known as the Whitney glacier; see Pl[illegible]



MOUNT SHASTA, CALIFORNIA.

GLACIERS OF NORTHERN CALIFORNIA AND THE CASCADE MOUNTAINS.

The Sierra Nevada is considered as terminating at the northward, near the northern boundary of California; but whether this is in reality the limit of the disturbance that elevated the range remains to be determined. The same great series of mountain forms so pronounced in northern California is continued northward as a prominent topographical feature through Oregon and Washington far into British America. North of California the chain has received the name of the Cascade Mountains, and, unlike the Sierra Nevada, is largely composed of quite recent lava. The volcanic overflows commence southward from what is generally considered as the southern extremity of the Cascade Range and form the grandest peaks in northern California. When the region is more thoroughly known perhaps the southerly peaks will be classed in the same range with Tacoma, Jefferson, Hood, etc. These grand cones, the glory of the Northwest coast, have been but imperfectly explored, yet enough is known to assure us that very many of them are glacier-crowned. Beginning at the south, we propose to present such observations as have been reported concerning the glaciers of the region.

MOUNT SHASTA.

The earliest account of the glaciers of Mount Shasta is given by Clarence King,[17] who ascended the peak in September, 1870, accompanied by several members of the United States Geological Exploration of the 40th Parallel. We transcribe entire the portion of his paper which relates directly to the glaciers:

"On September the 11th we climbed to the top of the lesser Shasta,[18] a conical secondary crater jutting out from the main mass of the mountain on its northwest side. * * * We reached the rim of the cone, and looked down into a deep gorge lying between the secondary crater and the main mass of Shasta, and saw directly beneath us a fine glacier, which started almost at the very crest of the main mountain, flowing towards us, and curving around the circular base of our cone.[19] Its entire length in view was not less than 3 miles, its width opposite our station about 4,000 feet, the surface here and there terribly broken in "cascades," and presenting all the characteristic features of similar glaciers elsewhere. The region of the terminal moraine was more extended than is usual in the Alps. The piles of rubbish superimposed upon the end of the ice indicated a much greater thickness of the glacier in former days. After finishing our observations upon the side crater, and spending a night upon the sharp edge of its rim, on the following morning we climbed over the divide to the main cone, and up to the extreme summit of Shasta, a point 14,440 feet above the sea level. From the crest I walked out to the northern edge of a prominent spur, and looked down upon the system of three considerable glaciers, the largest about 4½ miles in length and 2 or 3 miles wide. On the next day we descended upon the *south* side of the cone, following the ordinary track by which earlier parties have made the climb. From the moment we left the summit we encountered less and less snow, and at no part of the journey were we able to see a glacier. An east-and-west line divides the mountain into glacier-bearing and non-glacier-bearing halves. The ascent was formerly always made upon the north side, where, as stated, there are no glaciers, and this is why able scientific observers like Professor Whitney and his party should have scaled the mountain without discovering their existence.

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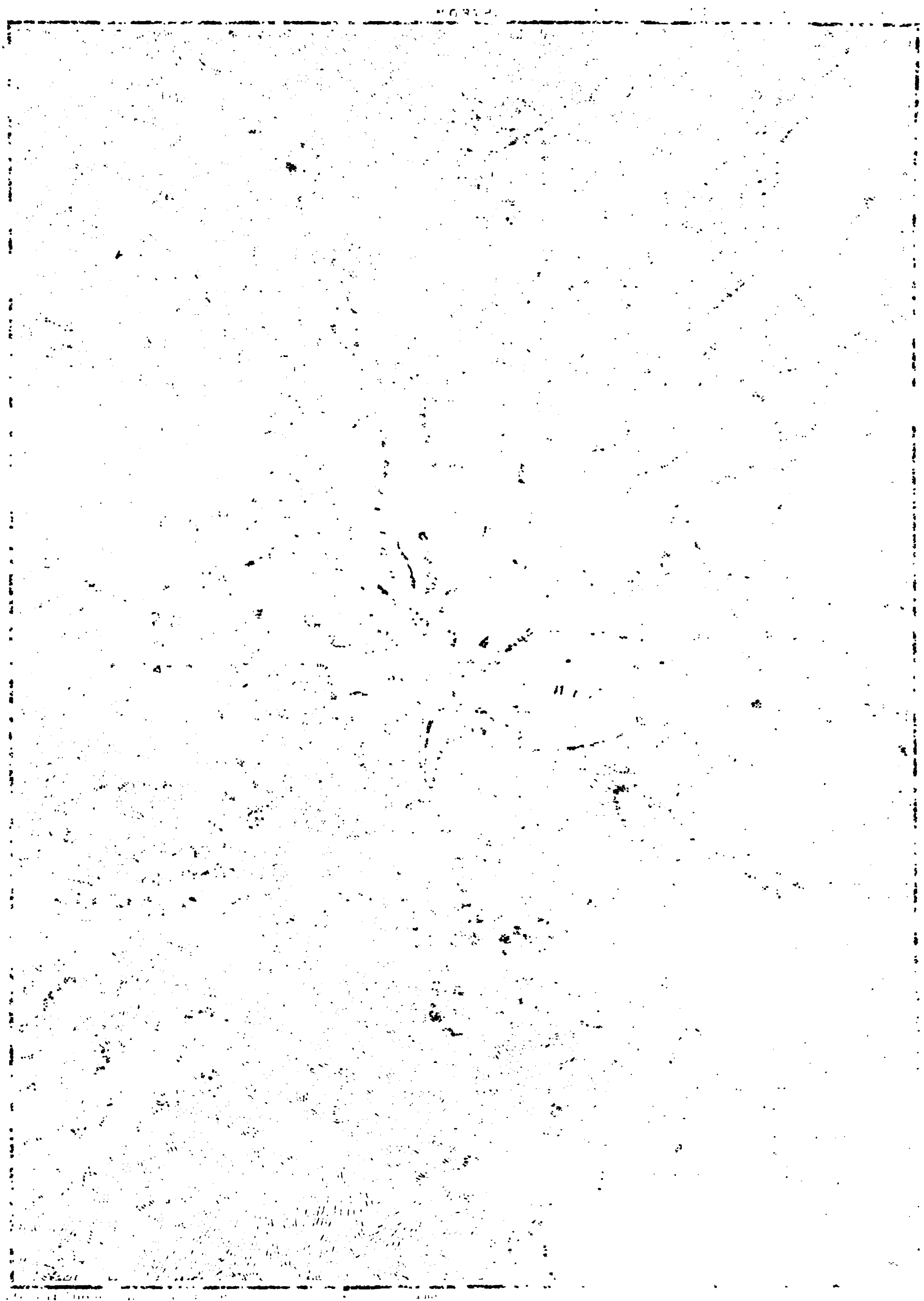
[17] American Jour. Sci., Vol. I, Third series, 1871, p. 157. A more popular account was published in "Mountaineering in the Sierra Nevada" by the same author.

[18] Named Shastina on the accompanying map. Plate XLIV.

[19] This is now known as the Whitney glacier; see Plate XLIV.

"Before and after the ascent of Mount Shasta, a week was given for an examination of the southern half of the volcano. Since the earliest settlement of Strawberry and Shasta Valleys, there has never been such a complete denudation. From June to November, the snow masses were less than they have ever been seen before. This favored very greatly our geological observations, and gave us an excellent opportunity to study the relics of the former great *névé*. We explored one after another all the cañons which, approximately following the radius of the cone, are carved to a greater or less depth into the lava-flows. From the secondary cone around to the eastern side of the main mass are only occasional fields of snow and ice-bodies of a thousand or two feet long, usually quite narrow and lying on the more shaded sides of the ravines. In nature and texture they are quite similar to the true glacier ice, possessing in all cases planes of stratification which indicate the pressure of the formerly overlying masses. There is little doubt that all the scattered snow-fields, that, in the months of August and September, dapple the southern slopes, are the relics of glaciers. They are found in the region of the ancient *névé*, but extending downward into what was formerly the zone of movement.

"Upon reaching the eastern side we found in a deep cañon a considerable glacier, having its origin in a broad *névé* which reaches to the very summit of the peak. The entire angle of this glacier can hardly be less than 28 degrees. It is one series of cascades, the whole front of the ice being crevassed in the most interesting manner. Near the lower end, divided by a boss of lava, it forks into two distinct bodies, one extending in an abrupt rounded face no less than 900 feet in height. Below this the other branch extends down the cañon for a mile and a half, covered throughout almost this entire length with loads of stones which are certainly falling in showers from the cañon walls on either side.



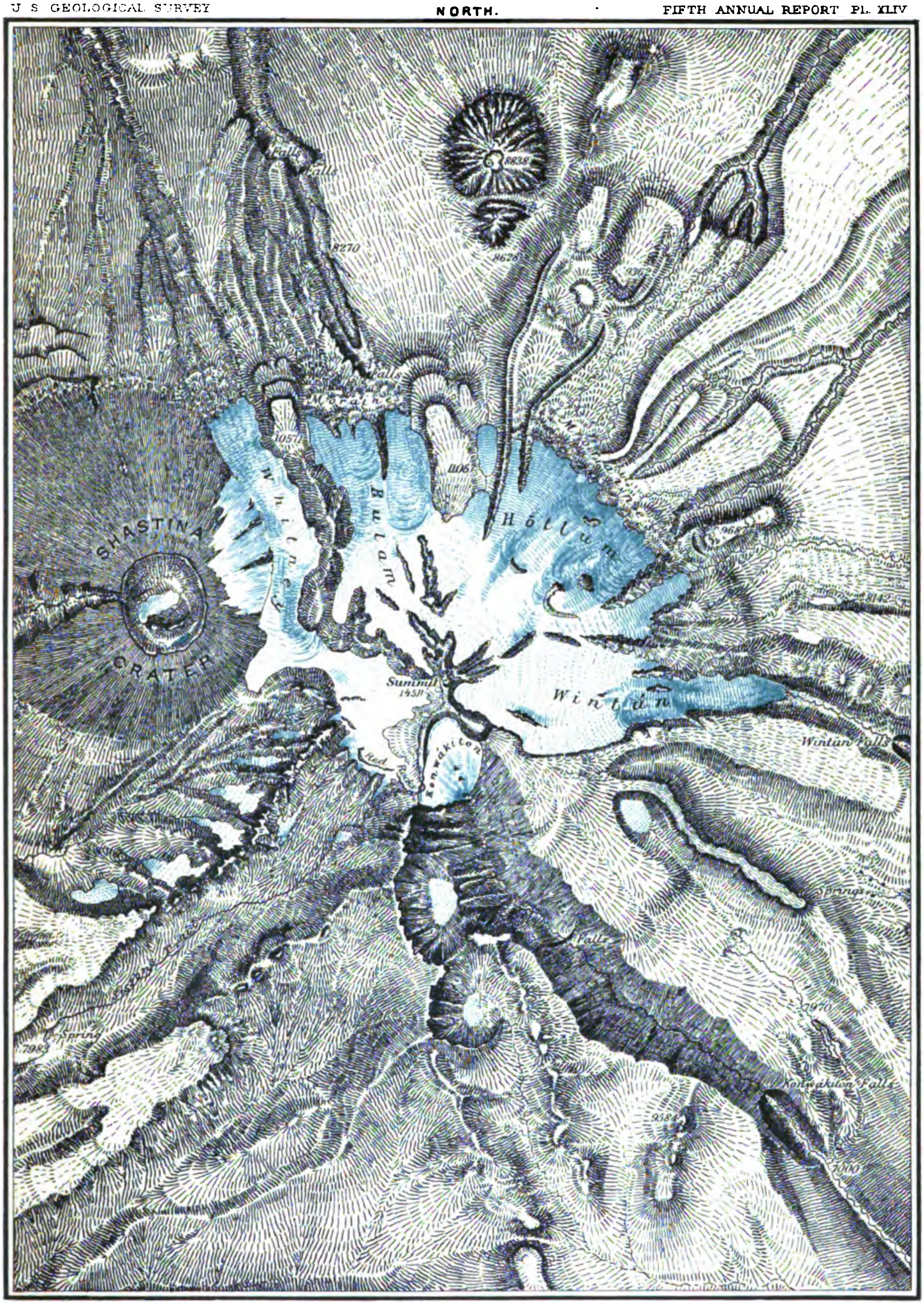
TOPOGRAPHICAL SKETCH OF [illegible]

[illegible] to a much greater thickness of the gla- [illegible] closing our observations upon the [illegible] [illegible] the sharp edge of its rim, on the [illegible] over the divide to the [illegible] and up [illegible] 14,440 feet above [illegible] sea level. [illegible] the eastern edge of a prominent spur, [illegible] of three considerable glaciers [illegible] [illegible] and 2 [illegible] 3 miles [illegible] [illegible] [illegible] of the cone, following the ordinary [illegible] [illegible] the present [illegible] and [illegible] at no part [illegible] An [illegible] West [illegible] [illegible] glacier [illegible] and [illegible] nearly [illegible] nearly always [illegible] on the [illegible] side, [illegible] this is [illegible] to ob- [illegible] party should have sealed the [illegible] their existence.

[illegible] week [illegible] [illegible] the volcano [illegible] [illegible] and Sesesa Valleys [illegible] [illegible] June to November, the snow masses were [illegible] This favored very greatly [illegible] observations, and gave us an excellent opportunity to [illegible] great névé. We explored [illegible] approximately following the [illegible] of the [illegible] or less depth into the [illegible] From [illegible] and to the eastern side of the main mass are [illegible] and ice bodies of a thousand or two feet long, [illegible] lying on the more secluded sides of the ravines. [illegible] to the [illegible] ice, pos- [illegible] stratification which indicate the pressure of [illegible] masses. There is little doubt that all these [illegible] in the months of August and September, despite the [illegible] of glaciers. They [illegible] downward into what was [illegible]

[illegible] eastern side we found in a deep cañon a consider- [illegible] origin in a broad névé [illegible] The entire angle of this glacier [illegible] series of cascades, the whole front of the ice [illegible] most interesting manner. Near the lower end, [illegible] it forks into two distinct [illegible] [illegible] face no less than 500 feet in height. Below [illegible] each extends down the cañon for a mile [illegible] half, [illegible] almost its entire length with loads of stones which [illegible] in showers from the cañon walls on either side.

NORTH.



Gilbert Thompson, Topographer

Julius Bien & Co. Lith.

TOPOGRAPHICAL SKETCH OF M^T SHASTA, CALIFORNIA, 1883.

Glaciers ■ Scale $\frac{1}{2534}$ one mile Névé Fields ▢

Indeed for a full mile the ice is only visible in occasional spots where cavities have been melted into its body, and loads of stones have fallen in. From an archway under the end a considerable stream flows out, milky, like the waters of the Swiss glacier streams, with suspended sand. Following around the eastern base of Shasta, we made our camps near the upper region of vegetation, where the forest and perpetual snow touch each other. A third glacier of somewhat greater extent than the one just described, was found upon the northeast slope of the mountain, and upon the north slope one of much greater dimensions. The exploration of this latter proved of very great interest in more ways than one. Receiving the snows of the entire north slope of the cone, it falls in a great field, covering the slope of the mountain for a breadth of about 3 or 4 miles, reaching down the cañons between 4 and 5 miles, its lower edge dividing into a number of lesser ice-streams which occupy the beds of the cañons. This mass is sufficiently large to partake of the convexity of the cone, and, judging from the depth of the cañons upon the south and southeast slopes of the mountain, the thickness cannot be less than from 1,800 to 2,500 feet. It is crevassed in a series of immense chasms, some of them 2,000 feet long by 30 and even 50 feet wide. In one or two places the whole surface is broken with concentric systems of fissures, and these are invaded by a set of radial breaks which shatter the ice into a confusion of immense blocks. Snow bridges similar to those in the Swiss glaciers are the only means of crossing these chasms, and lend a spice of danger to the whole examination. The region of the terminal moraines is quite unlike that of the Alps, a larger portion of the glacier itself being covered by loads of angular débris. The whole north face of the mountain is one great body of ice, interrupted by a few sharp lava ridges which project above its general level. The veins of blue ice, the planes of stratification, were distinctly observed, but neither *moulins* nor regular dirt-bands are present. Numerous streams, however, flow over the surface of the ice, but they happen to pour into crevasses which are at present quite wide.

" One of the most interesting of all the features of the country was, however, the clearly-defined moraines of the ancient and more widely extended glacier system. Nearly the whole topography of the lower part of the cone is modified by the deposition of glacial material. At an elevation of about 8,000 feet upon the northern or snowless side of the mountain, is a great plateau-like terrace, 2,500 or 3,000 feet wide, extending around one-half of the cone and composed wholly of moraine material. Besides these, long, straight, or slightly-curved medial moraines jut from the mountain in all directions, not unfrequently descending into the valley for several miles."

A brief account of the glaciers of Mount Shasta was contributed by King to an article on gravel ridges in the Merrimack Valley, from the pen of G. F. Wright,[20] in which special attention is given to the moraines now forming on the margins of the glaciers, and their resemblance to certain glacial deposits of New England.

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[20] Proceedings of the Boston Soc. of Nat. Hist., Vol. XIX, 1876, p. 60.

In the account of an ascent of Mount Shasta, published in the reports of the Geological Survey of California,[21] no mention is made of the existence of glaciers. In Professor Whitney's recent work, Climatic Changes of Later Geological Time,[22] an account of these glaciers is introduced, but it contains no observations in addition to those already published by King.

In 1882 a topographical survey of the region about Mount Shasta was begun by Mr. Gilbert Thompson, of the U. S. Geological Survey, who has kindly furnished the following notes and sketches, which form an addition to the previous descriptions of the mountain:

"During a portion of the season of 1883 I was engaged in obtaining the topographical details of Mount Shasta, California, and take pleasure in furnishing such information as I can concerning the glaciers now existing on the mountain.

"Mount Shasta is a volcanic peak situated in latitude 41° 24′ 30″, longitude 122° 11′ 34″. The present determination of its altitude above the sea is 14,511 feet.[23] It stands alone and has no connection with neighboring mountains, none of which within a radius of 40 miles attain two-thirds its height. The greatest length of its northwest slope, terminated by little Shasta Valley, which has an altitude of 3,000 feet, is 16 miles. The southwest slope reaches Elk Flat, and descends over 10,000 feet in 8 miles. The highest divide to the northwest is 6 miles distant, and has an altitude of 6,000 feet. The divide of the Sacramento River, 10 miles to the westward, is 3,500 feet above the sea. The ordinates from the summit to the contour of 8,000 feet will vary from 3 to 4 miles in length. The point where the timber growth receives its first check is at an elevation of 8,200 feet; the last tree, however, so diminutive as to hardly cover the palm of one's hand, was found at the altitude of 10,130 feet. Mount Shasta attracts the attention at a distance of over 100 miles, and from nearer points the solemn repose and grandeur of its isolation are impressive.

"The glaciers about the summit of Mount Shasta do not exist under the protection of sheltering cliffs or in the depth of cañons, but occur on the flanks of the mountain and are exposed for three-fourths of the day to the full power of the sun. The streams, having their origin in the melting of the snow, appear suddenly at the foot of the mountain as rushing torrents, loaded with silt; these subside during the latter part of the night and leave pools of clear water, which also gradually disappear. The water again reaches the surface in unexpected places many miles distant as immense springs. The stream channels are thus flooded once a day during the summer, and after the first snow, which occurs about the 1st of October, no more water descends from the snow-fields.

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[21] Vol. 1 (Geology), pp. 332–351.

[22] Page 27.

[23] Elevation determined with cistern barometer.

KONWAKITON GLACIER, MOUNT SHASTA, CALIFORNIA.

[illegible] the glaciers, and their [illegible] New England.

[illegible] published in the reports [illegible] is [illegible] the exist- [illegible] work [illegible] glaciers [illegible] to those [illegible]

[illegible] around Mount [illegible] U. S. Geological Survey [illegible] which [illegible] the mountain: [illegible] and [illegible] glaciers [illegible]

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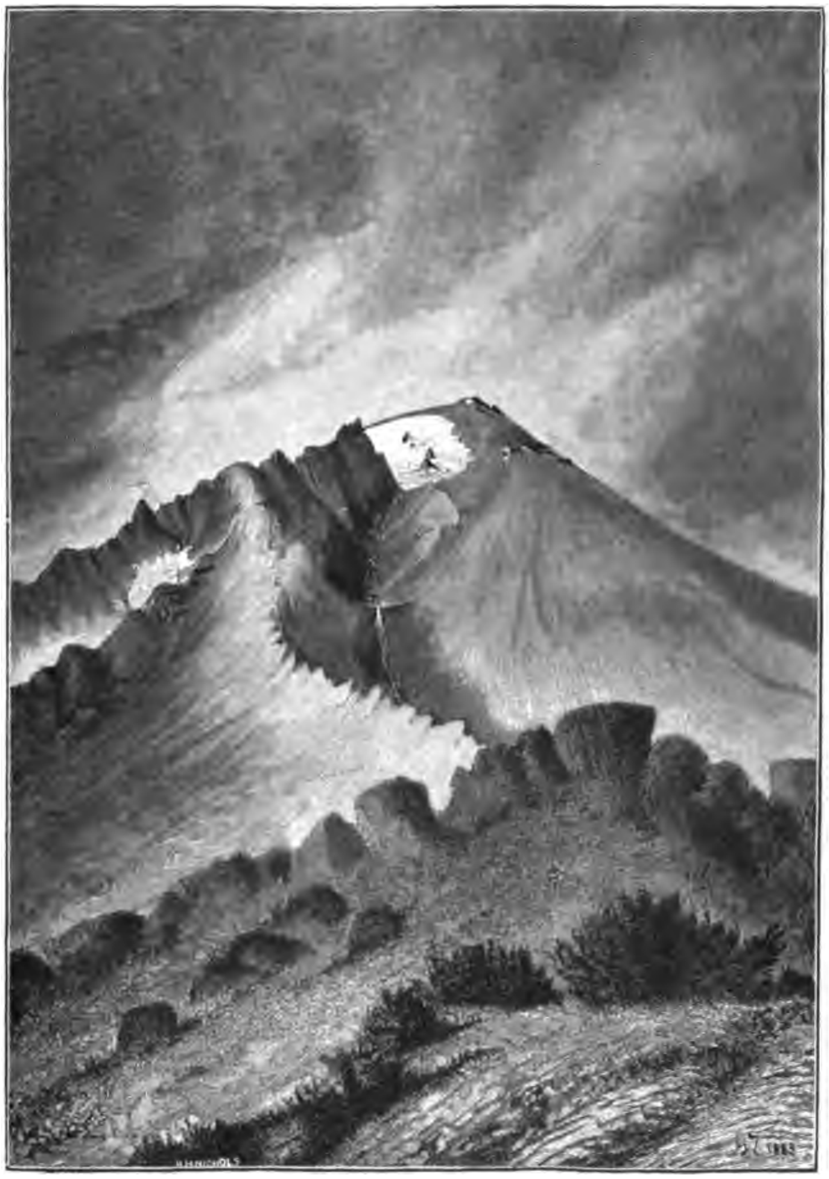
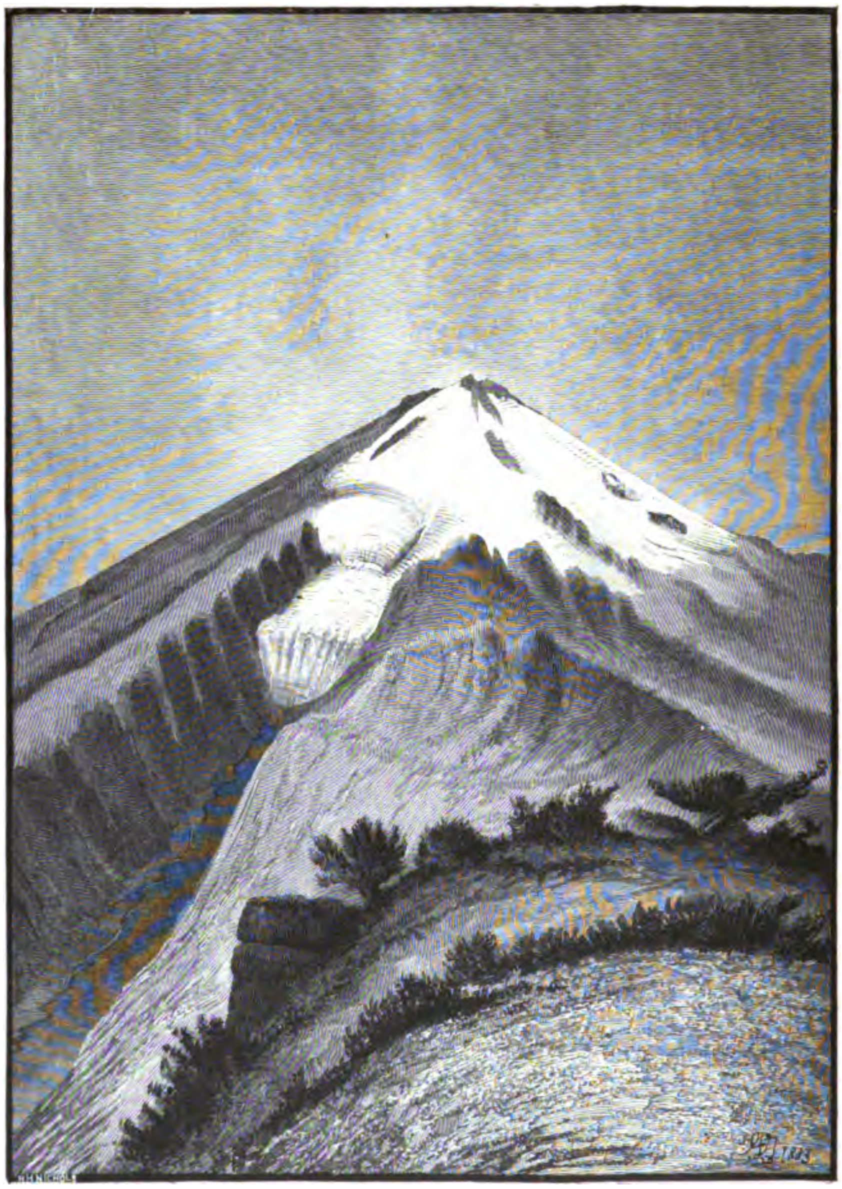


KONWAKITON GLACIER, MOUNT SHASTA, CALIFORNIA.



WINTUN GLACIER, MOUNT SHASTA, CALIFORNIA.

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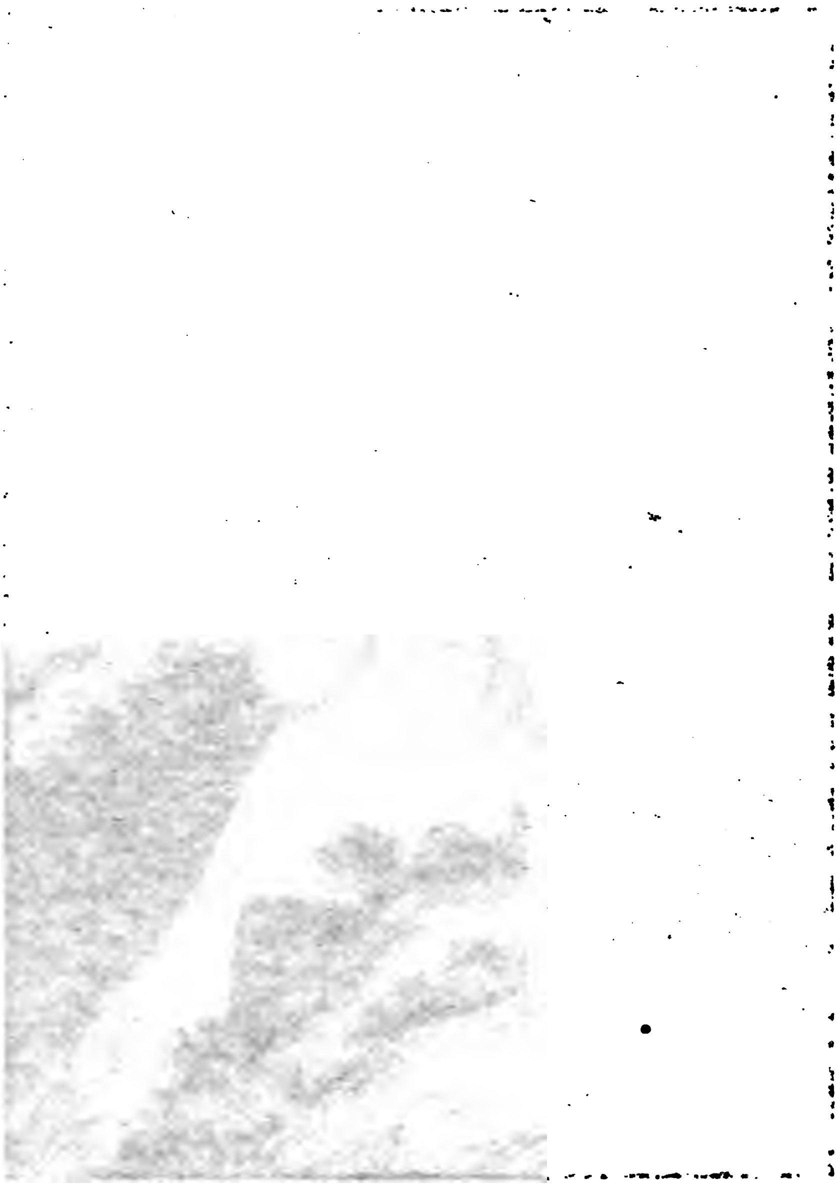
[illegible] fills a basin at the head of [illegible] altitude of about 22,000 [illegible] down the gorge, at [illegible] with boulders and [illegible] to the [illegible] a lower altitude it [illegible] height. The surface of this [illegible] yards. [illegible] the [illegible] forced to make a short detour [illegible] it is [illegible] separated from the wall of [illegible]

"The W[illegible] Glacier [illegible] average breadth of 1,000 [illegible] over [illegible] ing crevasses [illegible] cases [illegible] structure of great [illegible] a true ice [illegible] ice [illegible] accompany [illegible] A [illegible] material [illegible] ice [illegible]. The glacier [illegible] it [illegible] a considerable [illegible] the lower portion [illegible] there [illegible] many [illegible]

[illegible] moraines, at [illegible] points, [illegible] the lower [illegible]



S. GLACIER MO [illegible]

"Besides a few snow-banks that last throughout the year, and a few small glaciers in the shadow of protecting cliffs, there are five ice-streams which especially invite attention. With the exception of the Whitney Glacier, which was named in honor of the former State geologist of California, these have been designated by the following Wintun names: Konwakiton (mud glacier), Wintun (Indian tribal name), Hotlum (steep-rock), and Bolam (great).

"The Konwakiton Glacier is situated on the southeastern slope, and fills a basin at the head of a deep and rugged cañon. Its foot is at the altitude of about 12,000 feet, and from beneath it a strong stream flows down the gorge, at times disappearing beneath a flooring of ice covered with bowlders and débris derived from the walls that overshadow it. On reference to the topographic sketch (Plate XLIV) it will be seen that this stream falls in a cascade in the upper portion of the cañon; at a lower altitude it forms another beautiful waterfall about 400 feet in height. The surface of this glacier has an area of about 320,000 square yards. When making the ascent by Sisson's southern foot-trail, just as the weary climber turns the "Red Rocks" at 13,000 feet altitude, he is forced to make a short détour on the *névé* of this glacier, which is usually separated from the wall of rock by a deep crevasse.

"The Wintun Glacier has an area of about 2,000,000 square yards, an average breadth of 1,000 yards, and is 3,400 yards in length. In its course it flows over two precipices and becomes greatly broken by curving crevasses inclosing huge blocks and pinnacles of ice. These are veritable ice-cascades of no mean proportions, affording details of glacial structure of great beauty and interest. Near its terminus the glacier forms a true ice-stream, confined by cañon-walls, and finally terminates in an ice-foot several hundred feet high, which, as indicated in the accompanying sketch, is furrowed by numerous stream-cut channels A close approach to the ice-wall is dangerous because of the stones and morainal material that, at least in summer, are constantly falling as the ice melts. The glacier terminates at an altitude of about 8,000 feet, and from it flows a considerable stream which is always loaded with mud and silt. Some distance below the terminus this yellow stream forms a cascade fully 400 feet in height. The walls of the cañon occupied by the lower portion of this glacier, in common with nearly all the flanks of Mount Shasta, are somber in color and unpicturesque; below the falls, however, there are many points of view that will hold the attention and excite the enthusiasm of the traveler.

"The Hotlum Glacier is situated northward of the Wintun and separated from it by a series of narrow and precipitous spurs. On the north it is bounded by a narrow crest of rock which at first glance might be taken to be a medial moraine. The foot of this glacier ends in an arc of terminal moraines, at an altitude of 10,500 feet, which at certain points rests upon the lower portion of the ice. A thousand streams formed by the melting glacier find their way over and through the débris field, and render it a treacherous *terrain* to explore.

"Through the *névé* of the Hotlum Glacier two ice-streams may be said to flow, one of which, in crowding past two rocky buttresses, is broken into pinnacles of ice 50 to 60 feet in height, which are of a pearly-blue tint and present a fantastic and beautiful spectacle. The crevasses below the rocks are very deep and wide. Associated with them are wells of water of great depth, having a translucent blue color; these were oval in shape, the longer axis being in the direction of the flow of the glacier. The glacier is 2,500 yards in length, and covers an area of about 3,200,000 square yards.

"The Bolam Glacier, situated on the northern face of the mountain, indicates by the magnitude of its terminal moraine that it carries greater floods of débris than any of its associated ice-streams. At the time of my examination the foot of this glacier had retreated to a considerable distance from the terminal moraines and was divided into two flows. The first crevasse in this glacier occurs at an elevation of about 11,000 feet, and is of great width, length, and depth. From this rent to the terminus of the glacier the ice is broken into rough blocks and is deeply seamed with fissures. The Bolam Glacier is about 3,200 yards in length and approximately 1,800,000 square yards in area. The crest of the terminal moraine skirting its lower limit has an altitude of 10,000 feet.

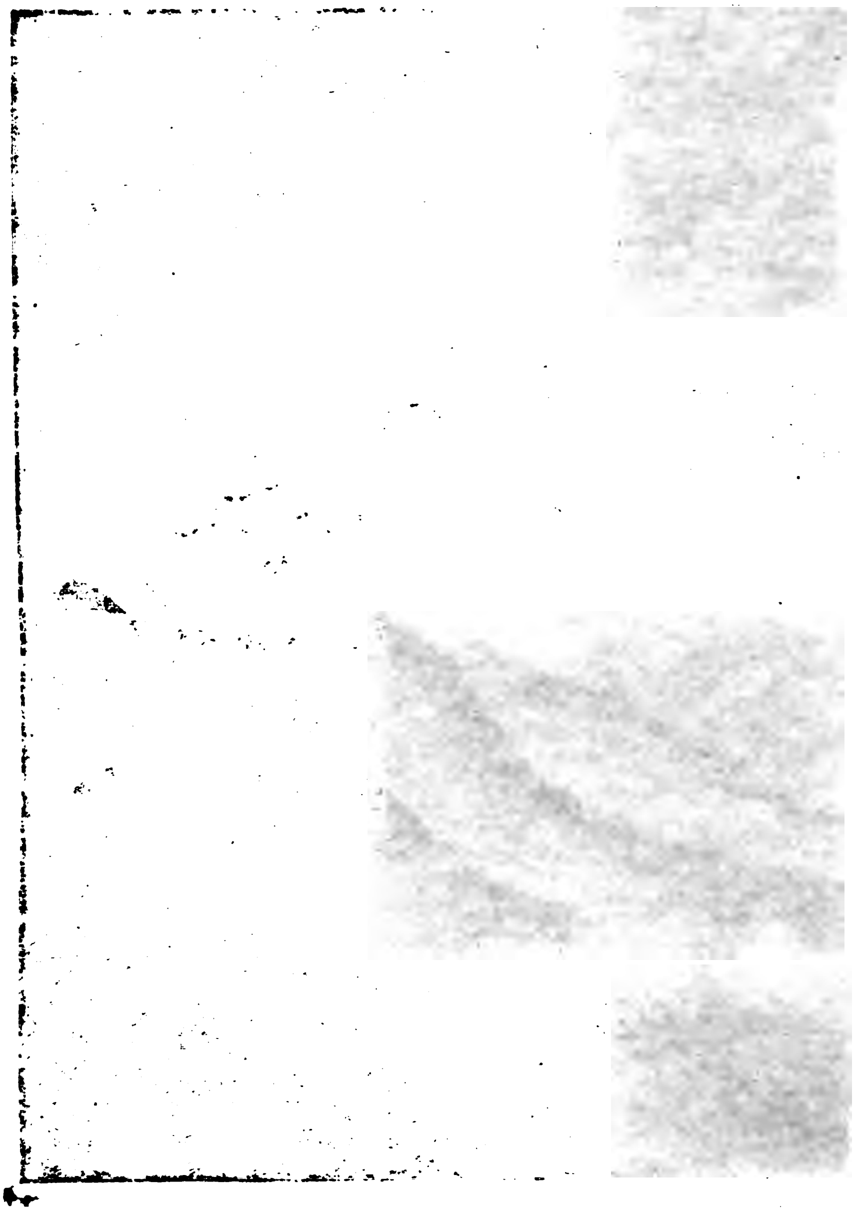
"To the right of the Bolam Glacier, as represented on Plate XLVIII, a portion of the Whitney Glacier is shown. This is the most typical ice-stream on the mountain, and originates in the *névé* lying on the table at the summit of the peak. In crowding past the east base of Shastina crater, which it has partially undermined, it occasions a constant falling of rocks and débris, and becomes broken into a multitude of blocks, which are reunited as the stream flows on. The Whitney Glacier is 3,800 yards in length and covers an area of 1,900,000 square yards; in October, 1883, its terminus was at an elevation of 9,500 feet above the sea.

"A careful examination of some of the ice-bodies on the western flank of Mount Shasta would perhaps lead to their being classed as glaciers of secondary magnitude; they occur on steep slopes at high altitudes, and all are over 700 feet in length.

"At the time of Mr. King's examination, in 1870, Mr. Watkins, of San Francisco, obtained a number of photographs of Mount Shasta, from a careful examination of which I conclude that there was more snow on the mountain when they were taken than at the time of my visit in 1883; this conclusion is also sustained by the statements of the residents in the vicinity."

MOUNT RAINIER.

In the Proceedings of the California Academy of Sciences for March 6, 1871, it is stated by Professor Davidson that Lieutenant, now General, August V. Kautz, U. S. A., attempted the ascent of Mount Rainier in 1857, but found his way barred by a great glacier. So far as can



HOTLUM GLACIER

[illegible] melting glacier find their way over and through the dé-[illegible] render it a treacherous *terrain* to explore.

[illegible] the *névé* of the Hotlum Glacier two ice streams may be said [illegible] of which, in crowding past two rocky buttresses, is broken [illegible] to 60 feet in height, which are of a pearly-blue [illegible] fantastic and beautiful spectacle. The crevasses be-[illegible] very deep and wide. Associated with them are wells [illegible] depth, having a translucent blue color; these were oval [illegible] axis being in the direction of the flow of the glacier. [illegible] 2,000 yards in length, and covers an area of about 3,200,000 [illegible].

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MOUNT RAINIER.

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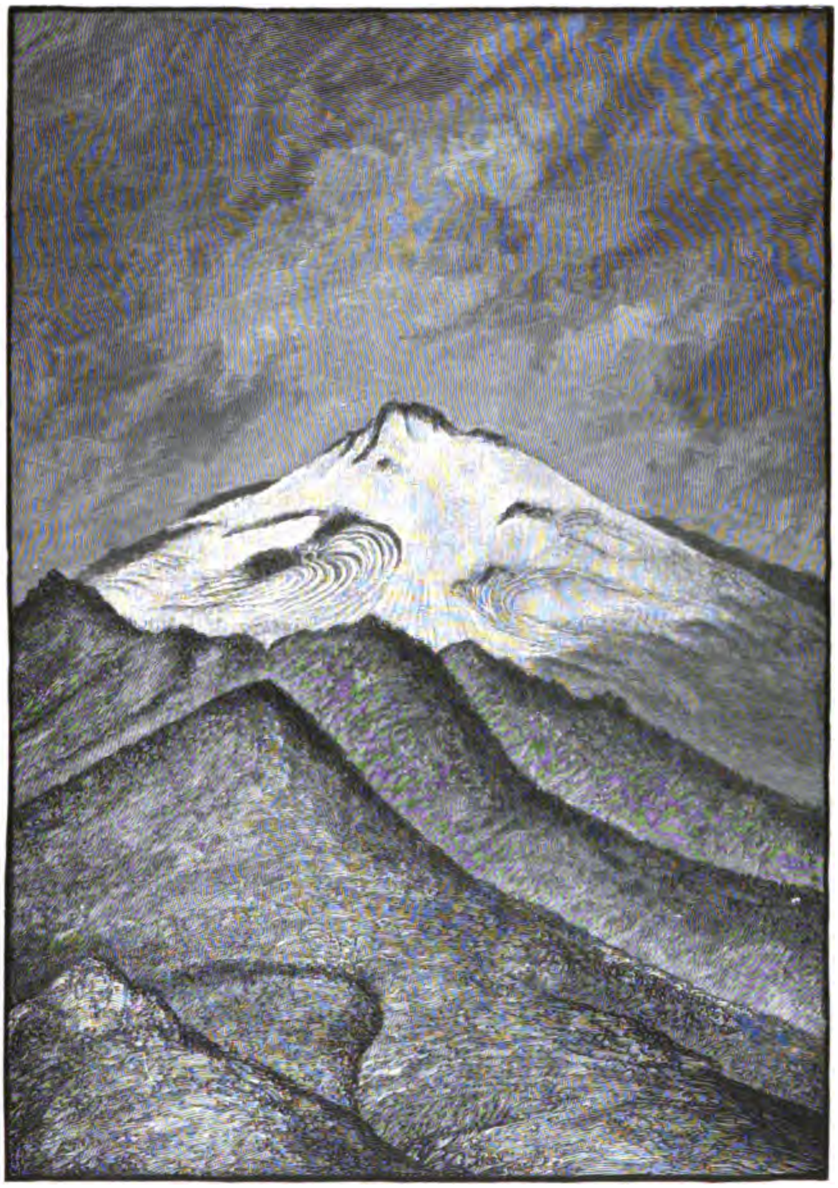
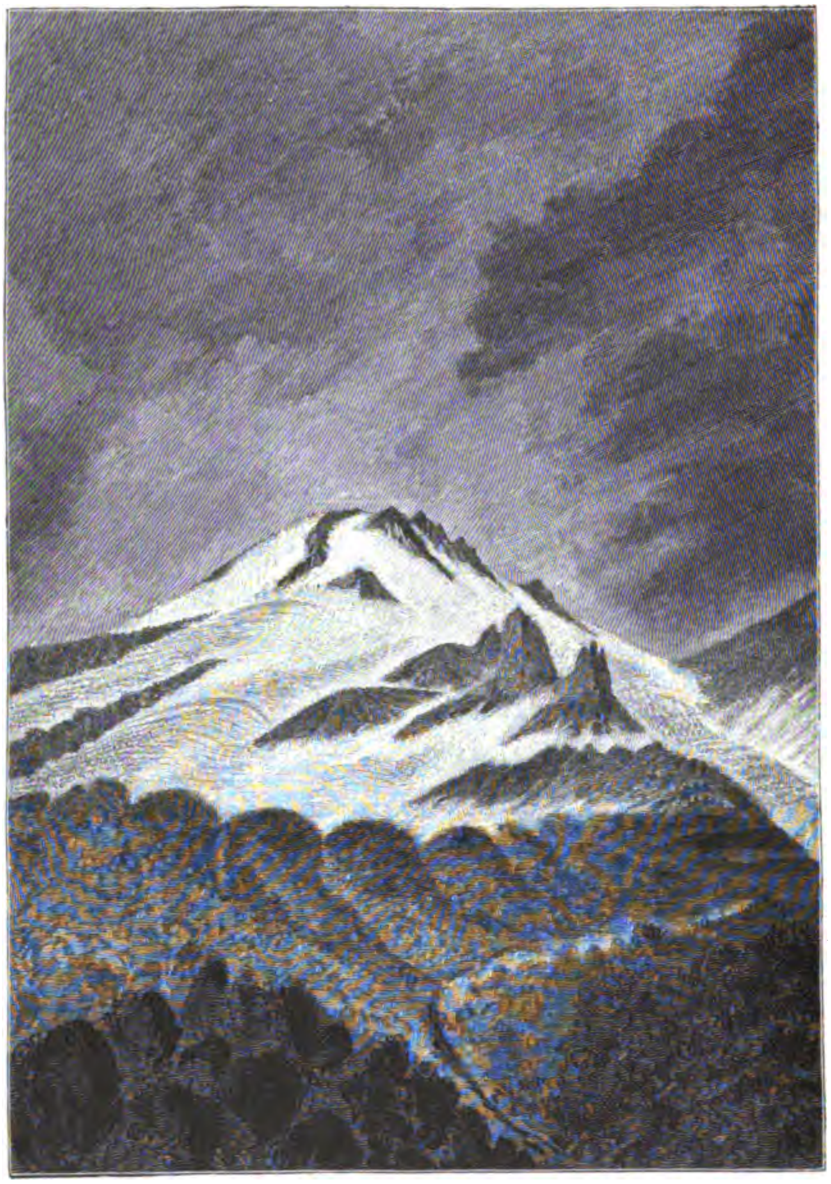


HOTLUM GLACIER, MOUNT SHASTA, CALIFORNIA.



BOLAM GLACIER, MOUNT SHASTA, CALIFORNIA.

be ascertained [illegible] perfect, but [illegible] [illegible] abstract of [illegible] by S. F. [illegible] ciety," but it contains [illegible] glacier scenery [illegible]

[illegible] Washington Territory.

Pacific Coast of the United [illegible] of the ascent of Mount Rainier [illegible] includes many observations [illegible] of the mountain. As [illegible] was contributed by Mr. [illegible] the Pacific slope we shall [illegible] an essay read before the Geo[illegible]

"[illegible] glaciers of Mount Tacoma [illegible] [illegible] form the principal sources of [illegible] important [illegible] tan Territory, viz. the [illegible] which flows into the [illegible] Nesqually, Puyallup, and [illegible] Rivers which empty into [illegible]

* * * * * *

The summit of Tacoma [illegible]

[illegible] Amer. [illegible]
[illegible]

[illegible]

MOUNT SHASTA, CALIFORNIA.

be ascertained no published account of Kautz's observations has appeared, but from Professor Davidson's statement it seems that he first reported the existence of living glaciers in the United States. An abstract of General Kautz's manuscript account of his excursion is given by S. F. Emmons in an address before the American Geographical Society,[24] but it contains no information of special interest concerning the glacier seen. The address referred to, entitled "The Volcanoes of the Pacific Coast of the United States," is devoted mainly to a description of the ascent of Mount Rainier by Mr. Emmons in October, 1870, and includes many observations on the glacier examined during his survey of the mountain. As a more detailed and exact account of these glaciers was contributed by Mr. Emmons to Mr. King's article on the glaciers of the Pacific slope,[25] we shall quote from it in preference to the more popular essay read before the Geographical Society:

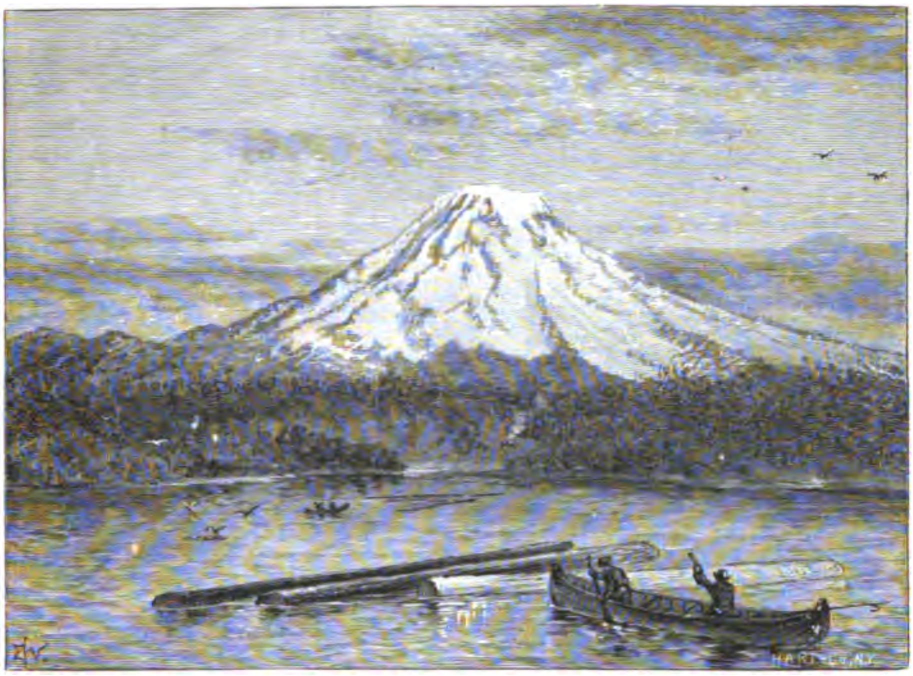


FIG. 140.—Mount Rainier, Washington Territory.

"The glaciers of Mount Tachoma or Rainier as it is more commonly called, form the principal sources of four important rivers of Washington Territory, viz., the Cowlitz, which flows into the Columbia, and the Nisqually, Puyallup, and White Rivers which empty into Puget Sound.

* * * * * * *

The summit of Tachoma is formed by three peaks, a southern, an

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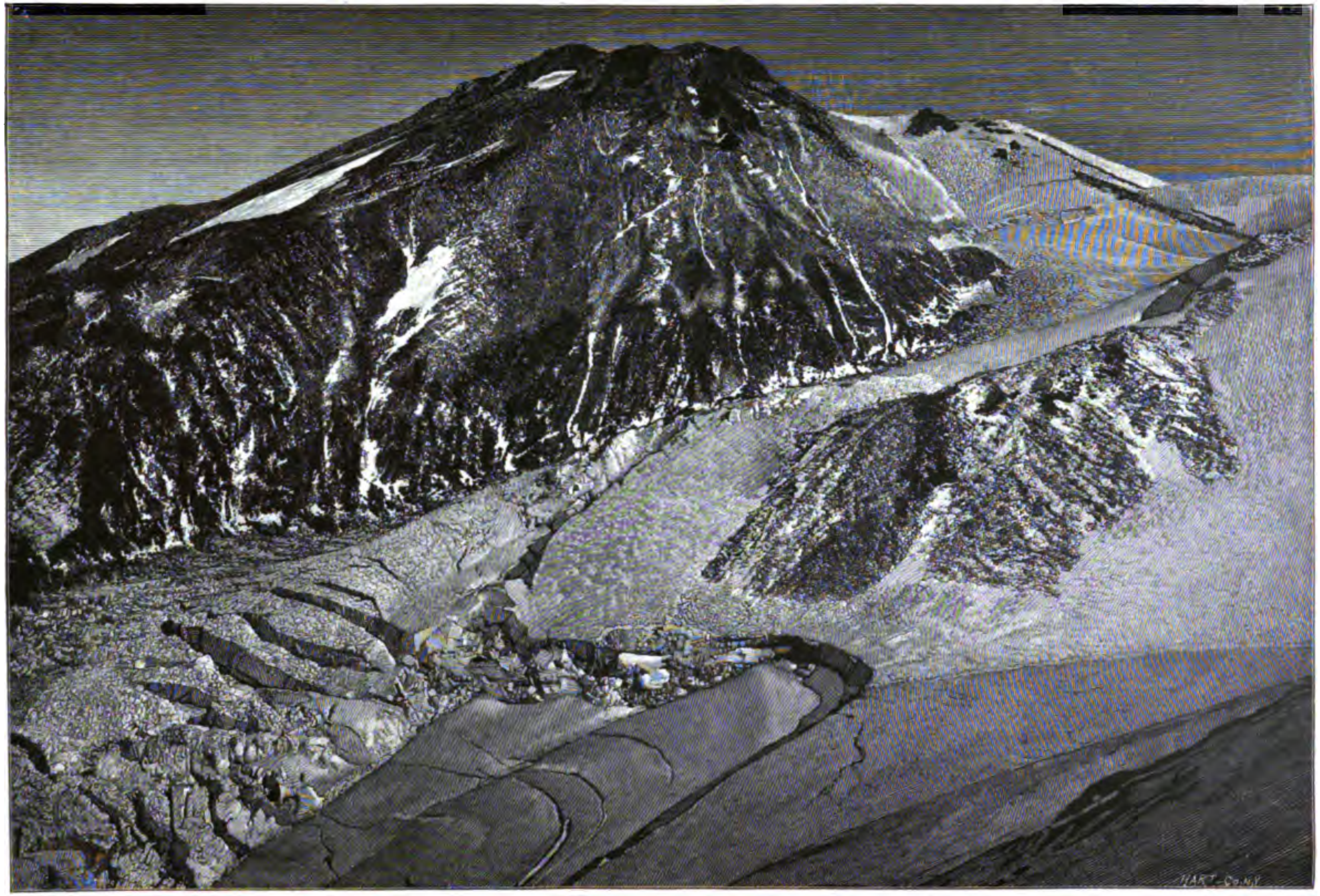
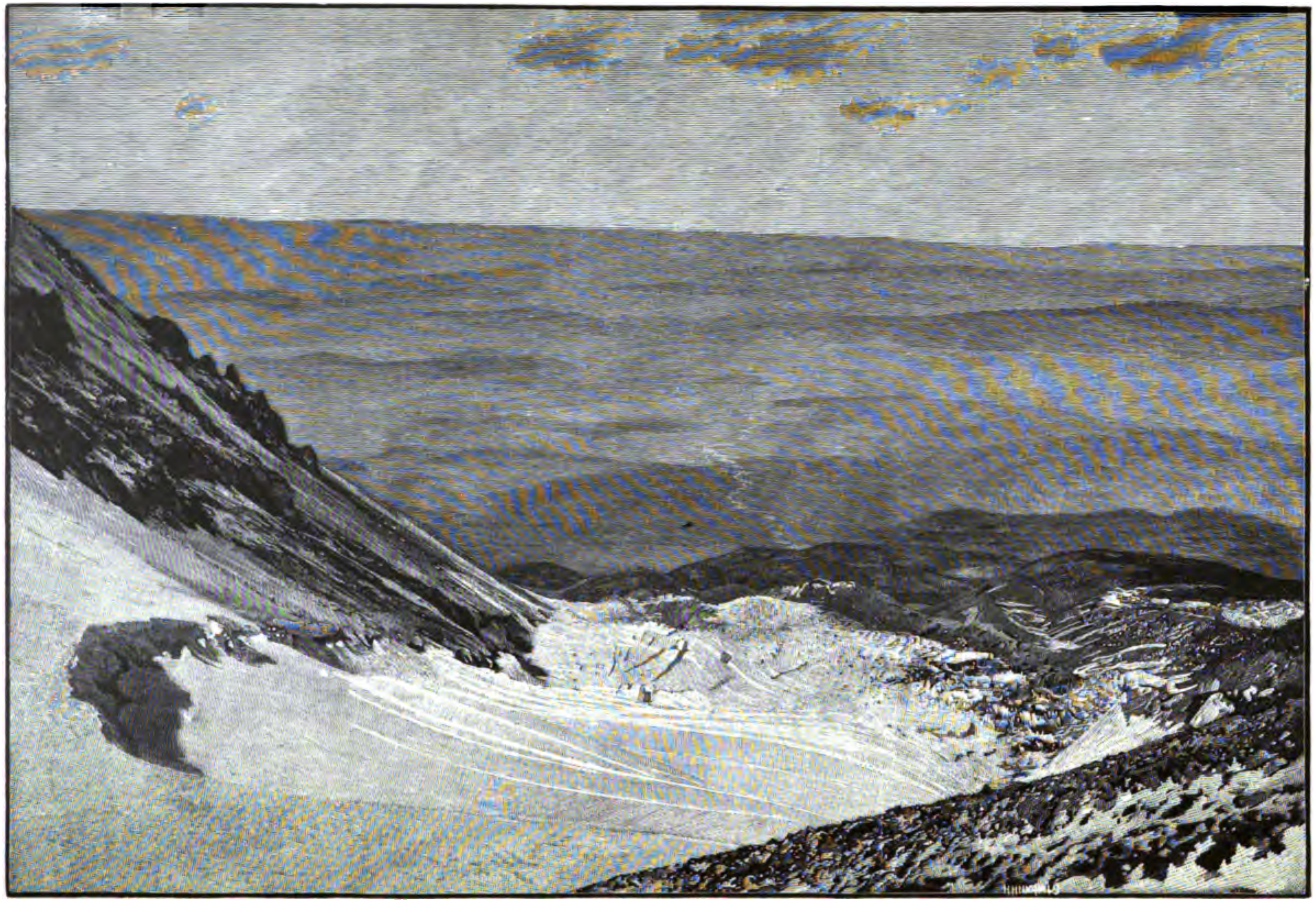
[24] Jour. Amer. Geographical Society, Vol. IX, p. 45.
[25] Amer. Jour. Sci., Third Series, Vol. I, 1871, p. 161.



HEAD OF WHITNEY GLACIER, MOUNT SHASTA, CALIFORNIA.



FOOT OF WHITNEY GLACIER, MOUNT SHASTA, CALIFORNIA.
(Looking north.)

[illegible]

[illegible] White River [illegible] secondary glaciers [illegible] semicircle [illegible] about 700 feet [illegible]

"A ridge of [illegible] Cascade Mountains [illegible] the White and Cowlitz Rivers [illegible] White River [illegible] already mentioned [illegible] two are, however, [illegible] originate [illegible] somewhat of an incline [illegible] of the glacier being of [illegible]

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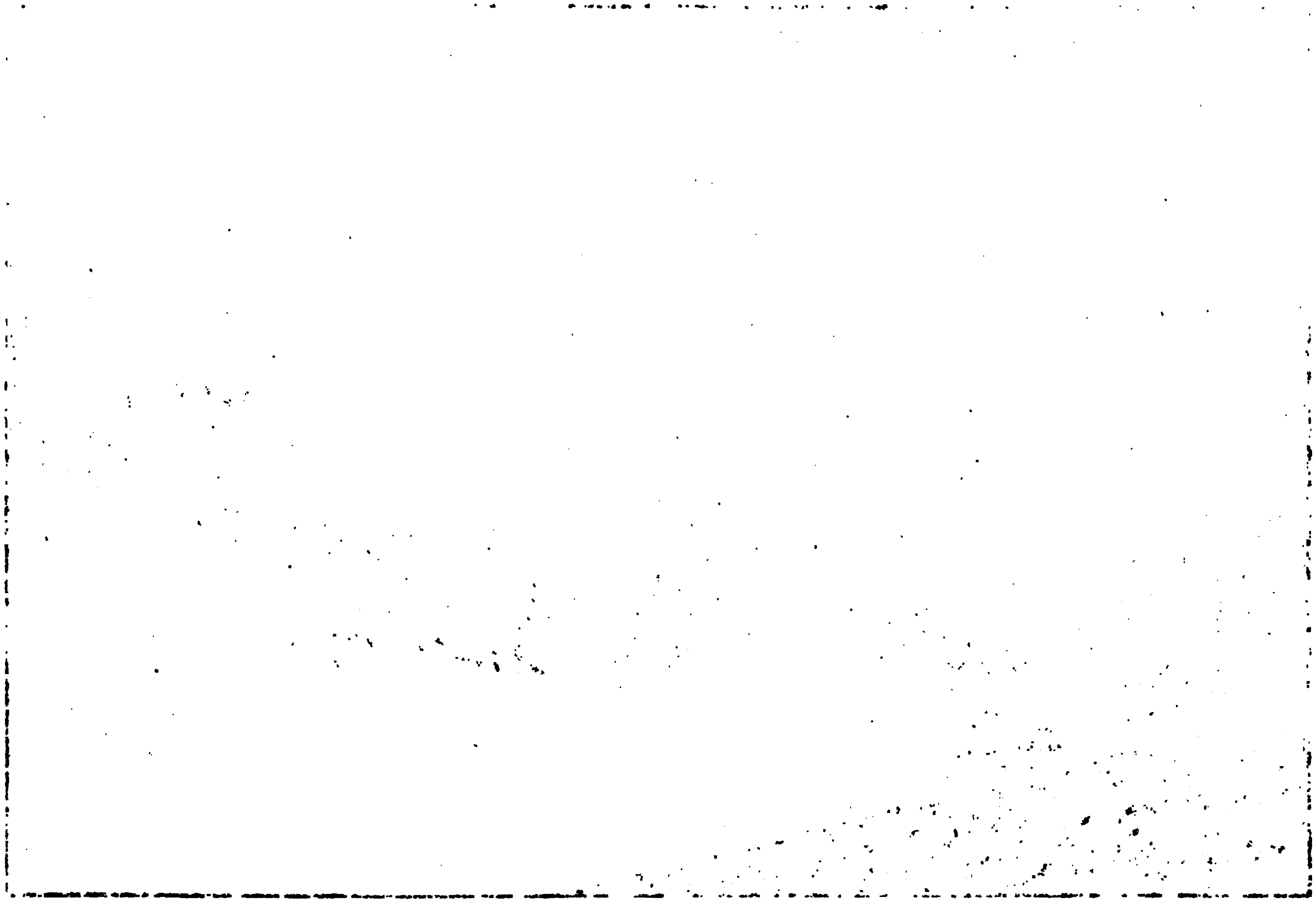

[illegible] WHITNEY GLACIER, MOUNT SHASTA, CALIFORNIA.

[illegible]

nobilis) for several hundred feet above the level of the ice, while the *Pinus flexilis* grows at least 2,000 feet higher than the mouth of the glacier.

"The general course of this glacier is south, but at its extremity it bends to the eastward, apparently deflected from its course by a cliff of older felsitic rock, more resisting than the lava. The consequence of this deflection is a predominance of longitudinal over transverse crevasses at this point, and an unusually large moraine at its western side, which rises several hundred feet above the surface of the glaciers and partakes of the character of both lateral and terminal moraines: the main medial moraine of the glacier joins this near its lower end. This medial moraine proceeds from the cliff which bounds the ice-cascades source of the glacier on the north, and brings down a dark, porous lava which is only found high up on the mountain near the crater. The position of the medial moraine on the glacier would indicate that at least half its mass came from the spur on the east, which is probably the case.

"This spur, comprehending the whole mass between the Cowlitz and White River Glaciers, has the shape of a triangle whose apex is formed by a huge pinnacle of rock, which as its bedding indicates, once formed part of the crest of the mountain, but now stands isolated, a jagged peak rising about 3,000 feet above the glaciers at its foot, so steep that neither ice or snow rest upon it. One of the tributaries to the Cowlitz Glacier from this spur brings down with it a second medial moraine, which is traceable to the mouth of the glacier, though in general these tributary glaciers bring no medial moraines.

"On the eastern slopes of this spur between the two above-named glaciers, spread secondary glaciers, frequently of great width, but owing to the limited height of their initial points, of inconsiderable length. These end generally in perpendicular cliffs overhanging the rocky amphitheaters at the heads of the smaller streams which flow eastward into the Cowlitz. Looking up from the bottom of one of these amphitheaters one sees a semi-circular wall of nearly 2,000 feet of sheer rock, surmounted by about 500 feet of ice, from under which small streams of water issue, falling in silvery cascades on to the green bottom below.

"A ridge of high jagged peaks connects this spur with the main range of the Cascade Mountains in the east, and forms the watershed between the White and Cowlitz Rivers. From the connecting saddle one can look northward across the brink of six glaciers, which all contribute to the White River; of these the first four come from the triangular spur already mentioned and are of comparatively little extent. The first two are, however, interesting from the vein structure which they exhibit; they both originate in an irregularly oblong basin, having the shape somewhat of an inclined ellipse, turning on its longer diameter, the outlets of the glacier being opposite the foci. Seen from a high point the veins form concentric lines generally parallel to the sides of the basin;

the ends of those towards the center gradually bend round until they join together in form of a figure 8, and finally just above the outlets form two small ellipses. They thus constantly preserve a direction at right angles to that of the pressure exerted downward by the movement of the ice-mass, and upward by the resistance to this movement of the rock mass between the two outlets.

"The main White River Glacier, the grandest of the whole, pours straight down from the rim of the crater in a northeasterly direction, and pushes its extremity farther out into the valley than any of the others. Its greatest width on the steep slope of the mountain must be 4 or 5 miles, narrowing towards its extremity to about a mile and a half; its length can be scarcely less than 10 miles. The great eroding power of glacial ice is strikingly illustrated in this glacier, which seems to have cut down and carried away as shown by the walls on either side, and the isolated peak at the head of the triangular spur, in which the bedding of the successive flows of lava, forming the original mountain crust, is very regular and conformable, may be roughly estimated at somewhat over a mile. Of the thickness of the ice of the glacier I have no data for making estimates, though it may probably be reckoned in thousands of feet.

"It has two principal medial moraines, which, where crossed by us, formed little mountain ridges having peaks nearly 100 feet high. The sources of these moraines are cliffs on the steeper mountain slope, which seem mere black specks in the great white field above: between these are great cascades, and below immense transverse crevasses, which we had no time or means to visit. The surface water flows in rills and brooks, on the lower portion of the glacier, and *moulins* are of frequent occurrence. We visited one double *moulin* where two brooks poured into two circular wells, each about 10 feet in diameter, joined together at the surface but separated below: we could not approach near enough the edge to see the bottom of either, but, as stones thrown in sent back no sound, judged they must be very deep.

"This glacier forks near the foot of the steeper mountain slope, and sends off a branch to the northward, which forms a large stream flowing down to join the main stream 15 or 20 miles below. Looking down on this from a high, over hanging peak, we could see, as it were, under our feet, a little lake of deep blue water, about an eighth of a mile in diameter, standing in the brown gravel-covered ice of the end of the glacier. On the back of the rocky spur, which divides these two glaciers, a secondary glacier has scooped out a basin-shaped bed, and sends down an ice-stream, having all the characteristics of a true glacier, but its ice disappears several miles above the mouths of the large glaciers on either side. Were nothing known of the movements of glaciers, an instance like this would seem to afford sufficient evidence that such movement exists, and that gravity is the main motive power. From our northern and southern points we could trace the beds of several large glaciers to the west of us, whose upper and lower portions only were visible, the main body of the ice lying hidden by the high intervening spurs.

"Ten large glaciers observed by us, and at least half as many more hidden by the mountain from our view, proceeding thus from an isolated peak, form a most remarkable system, and one worthy of a careful and detailed study."

A graphic account of an ascent of Tachoma (Rainier) was published in the Atlantic Monthly[26] by General Hazard Stevens, who ascended the peak in August, 1870.

Frequent references are made in this essay to the numerous ice-streams that originate on the mountain, but no detailed account of glacial phenomena is presented.

MOUNT HOOD.

In August, 1866, Prof. A. Wood ascended Mount Hood, and later in the year gave a short account of his observations before the California Academy of Sciences.[27] During his ascent he encountered chasms of invisible depth in solid blue ice, in which the rush of subglacial streams could be heard. From the summit of the peak it was observed that a deep cañon descended the southeast flank of the mountain, which was partly filled by a glacier evidently in motion. Both terminal and lateral moraines were seen on the border of the glacier, and a torrent of water issued from its terminus.

Mr. Arnold Hague, in his contribution to King's article on the glaciers of the Pacific coast,[28] already referred to, described the existing glaciers of Mount Hood as follows:

"The crater [of Mount Hood] is nearly one-half a mile wide from east to west. The wall upon the inner side rises above the snow and ice filling the basin some 450 feet, while upon the outer side it falls off abruptly for 2,000 feet. This rim of the crater is very narrow; in many places the crest is not more than 2 feet wide.

"Three distinct glaciers have their origin in this basin, each the source of a stream of considerable size; the glaciers of the White, the Sandy, and the Little Sandy Rivers.

"The White River Glacier heads on the eastern side of the crater, and extends in a southeasterly direction. It is nearly a quarter of a mile wide at the head, and about 2 miles long, extending 500 feet below the line of the timber-growth upon the side of the mountain.

"Near the top of the crater a broad transverse crevasse cuts entirely across the glacier. Freshly fallen snow overhangs its projecting banks, the perpendicular walls of ice, making it exceedingly dangerous to approach. At one point only, the fissure may be crossed by an ice bridge. Further down the slope of the glacier transverse crevasses are of frequent eastern, and a northwestern; of these the eastern is the highest; those on the south and northwest, being apparently a few hundred feet lower, are distant about a mile and a half to 2 miles from this, and separated by deep valleys. The eastern peak, which would seem to have formed originally the middle of the mountain mass, is a crater about a quarter of a mile in diameter of very perfect circular form. Its sides are bare for about 60 feet from the rim, below which they are covered by a *névé* having a slope of from 28° to 31°. This *névé* extending from the shoulders of the southwestern peak to those of the northern, a width of several miles, descends to a vertical distance of about 2,000 feet below the crater rim, an immense sheet of white granular ice, having the general form of the mountain surface, and broken only by long transverse crevasses, one of those observed being from 1 to 2 miles in length: it is then divided up by the several jutting rock masses or shoulders of the mountain into the Nisqually, Cowlitz, and White River glaciers, falling in distinct ice-cascades for about 3,000 feet at very steep angles, which sometimes approach the perpendicular. From the foot of these cascades flow the glaciers proper, at a more gentle angle, growing narrower and sinking deeper into the mountain as they descend. From the intervening spurs, which slope even more gradually, they receive many tributary glaciers, while some of these secondary glaciers form independent streams, which only join the main river many miles below the end of the glaciers.

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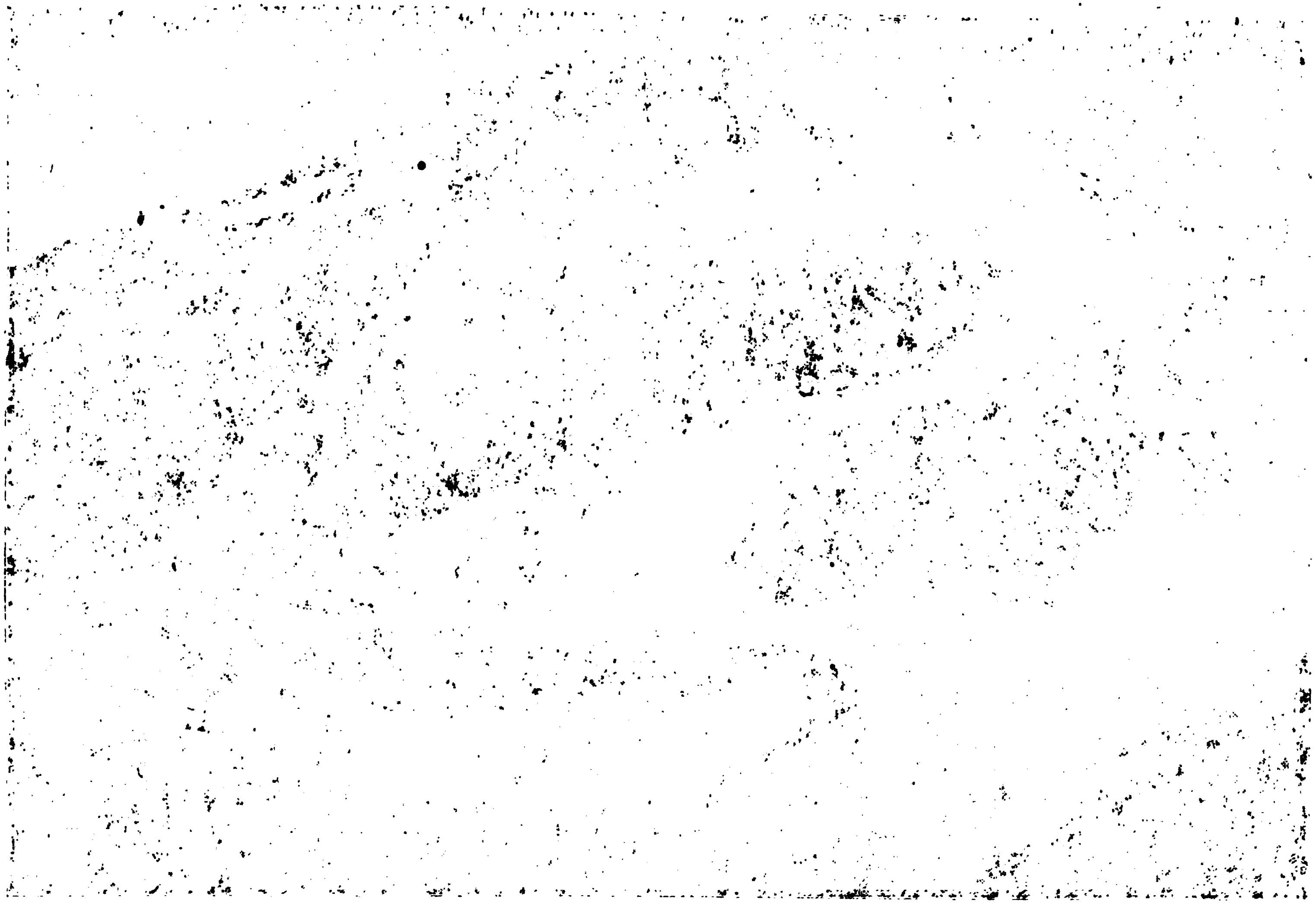
[26] Vol. XXXVIII, 1876, p. 513.

[27] Proceedings, Vol. III, p. 292.

[28] Amer. Jour. Sci., Third series, Vol. I, 1871, p. 165. *Ante*, p. 329.

"The Nisqually, the narrowest of the three main glaciers above mentioned, has the most sinuous course, varying in direction from southwest to south, while its lower extremity is somewhat west of south of the main peak: it receives most of its tributaries from the spur to the east, and has a comparatively regular slope in its whole length below the cascades. There are some indications of dirt-bands on its surface, when seen from a considerable elevation. Toward its lower end it is very much broken up by transverse and longitudinal crevasses: this is due to the fact, that it has here cut through the more yielding strata or volcanic rock, and come upon an underlying and unconformable mass of syenite. The ice-front at its base is about 500 feet in height, and the walls of lava which bound its sides, rise from 1,000 to 1,500 feet above the surface of the ice, generally in sheer precipices.

"The bed of the Cowlitz Glacier is generally parallel to that of the Nisqually, though its curves are less marked: the ice-cascades in which each originates, fall on either side of a black cliff of bedded lava and breccia scarcely a thousand feet in horizontal thickness, while the mouths of the glaciers, if I may be allowed the expression, are about 3 miles apart. From the jutting edge of this cliff hang enormous icicles from 75 to 100 feet in length. The slope of this glacier is less regular, being broken by subordinate ice-cascades. Like the Nisqually, its lower extremity stretches out as it were into the forest, the slopes on either side, where not too steep, being covered with the mountain fir (*Picea*



[illegible] WHITNEY GLACIER, MOUNT SHASTA, CALIFORNIA

PERMANENT ICE ON THE MOUNTAINS OF THE GREAT BASIN.

The arid region of interior drainage included between the Sierra Nevada and the Wasatch Mountains, known as the Great Basin, is diversified by many rugged mountain ranges, some of which attain an altitude of from 10,000 to more than 13,000 feet. The climate is arid and the country desert-like throughout, except along the margins of streams and where springs come to the surface. The valleys are usually scantily clothed with sage brush, but not infrequently they are absolute deserts, and the mountains, as a rule are bare of vegetation, especially about their more elevated portions. A region more unfavorable for the formation of glaciers could scarcely be found; yet, as shown by the observations of Mr. William Eimbeck, of the United States Coast Survey, there is a body of ice on Jeff Davis peak,[30] one of the highest mountains in the Great Basin, that approaches the condition of a glacier, and indicates that a moderate lowering of temperature would cause glaciers to form on the higher peaks in the central and northern part of the Great Basin. That a moderate climatic change would produce such a result is also evident from the fact that during the glacial epoch, when the higher mountains of Utah and California were buried beneath vast *néré* fields, some of the intermediate ranges, including Jeff Davis Peak, also bore glaciers.

Jeff Davis Peak has an altitude of 13,100 feet; rising 8,000 feet above the valleys that flank it on the east and west, and forming the crowning point of one of the most rugged of the basin ranges. It is situated in Eastern Nevada, about 15 miles from the Nevada-Utah boundary, or, more accurately, in latitude 38° 59′ and longitude 114° 19′, as deter-

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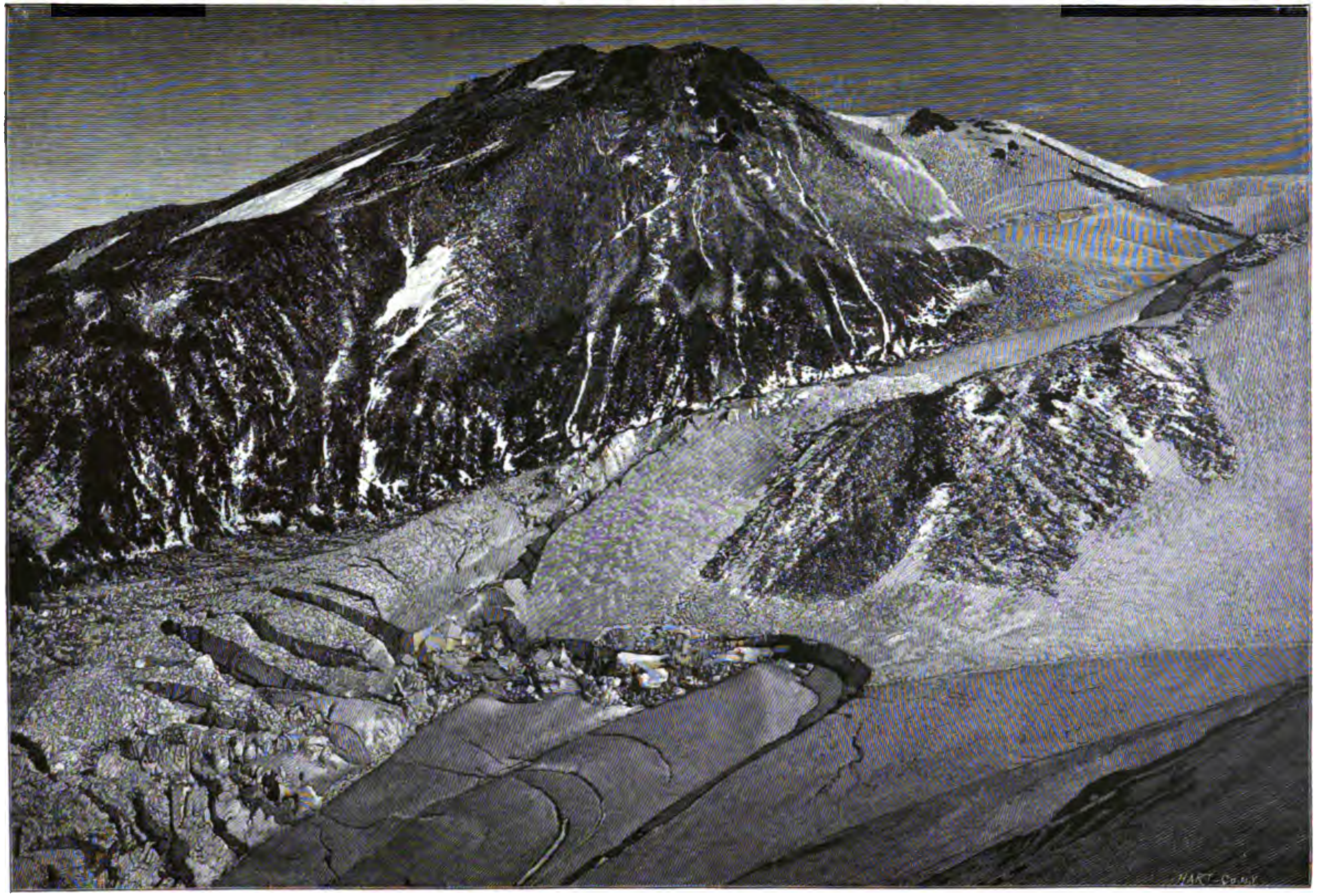
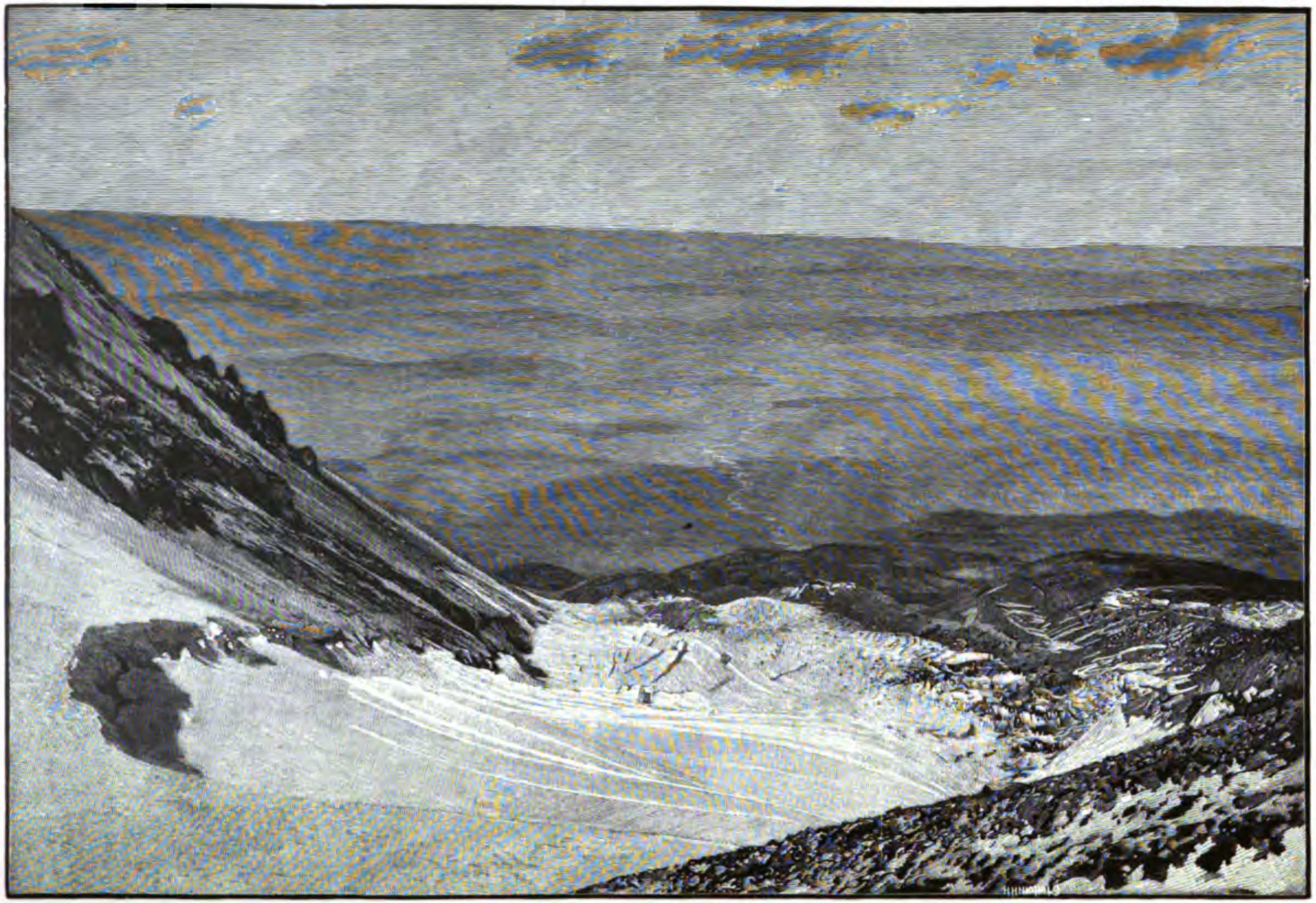
[30] This mountain has a number of synonyms. To the Indians it is known as "Too-bur-rit," and to the whites as "Union," "Jeff Davis," "Lincoln," and "Wheeler's" Peak. Capt. J. H. Simpson passed near it in 1859 and named it Union Peak, in reference to its double form when seen from the north. (See Simpson's "Exploration across the Great Basin of Utah in 1859," pages 51 and 121.) Among the settlers in the southern portions of Utah and Nevada it is generally known as Jeff Davis Peak. It is said that two miners, while exploring the mountain during the time of the late rebellion, one being of Southern and the other of Northern birth, named the two spires forming the summit of the mountain respectively Jeff Davis and Lincoln Peaks; by general consent the former has been adopted as the name of the mountain. In 1869 Lieut. G. M. Wheeler and party ascended the mountain, accompanied by Rev. A. F. White, acting State geologist of Nevada, who named it Wheeler's Peak. See "Report on a Reconnaissance in Southern and Southeastern Nevada," Engineer Dep., U. S. A., 1875, p. 62.

The presence of snow about this peak during the summer season was noticed by Captain Simpson, late in July, 1859. ("Exploration across the Great Basin of Utah in 1859," p. 51.)



HEAD OF WHITNEY GLACIER, MOUNT SHASTA, CALIFORNIA.



FOOT OF WHITNEY GLACIER, MOUNT SHASTA, CALIFORNIA.
(Looking north.)

nobilis, [illegible] several hundred feet above the level of the [illegible], while the *Pinus flexilis* grows at least [illegible] [illegible]

The general course of this glacier [illegible] older [illegible] rock, more resisting [illegible] The [illegible] is a [illegible] penetrated [illegible] western [illegible]

[illegible] whole [illegible] its bed [illegible] which [illegible] to the [illegible] tributary glaciers bring [illegible]

On the eastern slopes of [illegible] glaciers, or rather secondary glaciers, [illegible] covered by about 700 feet of [illegible]

A ridge of high jagged peaks [illegible] Cascade [illegible] the White and Cowlitz Rivers. [illegible] White River [illegible] two [illegible] however, [illegible] somewhat [illegible] lets of the glacier being [illegible]

EXISTING GLACIERS IN THE ROCKY MOUNTAINS.

It has long been known that very large portions of the Rocky Mountains bear evidence of former glaciation, but until quite recently no one had reported the existence of living glaciers in this region. Sierra Blanca, in Southern Colorado, retains patches of snow and ice throughout the year, and the same is true of a large number of the magnificent mountains in the central part of the same State; but no true glaciers have yet been discovered south of Central Wyoming.

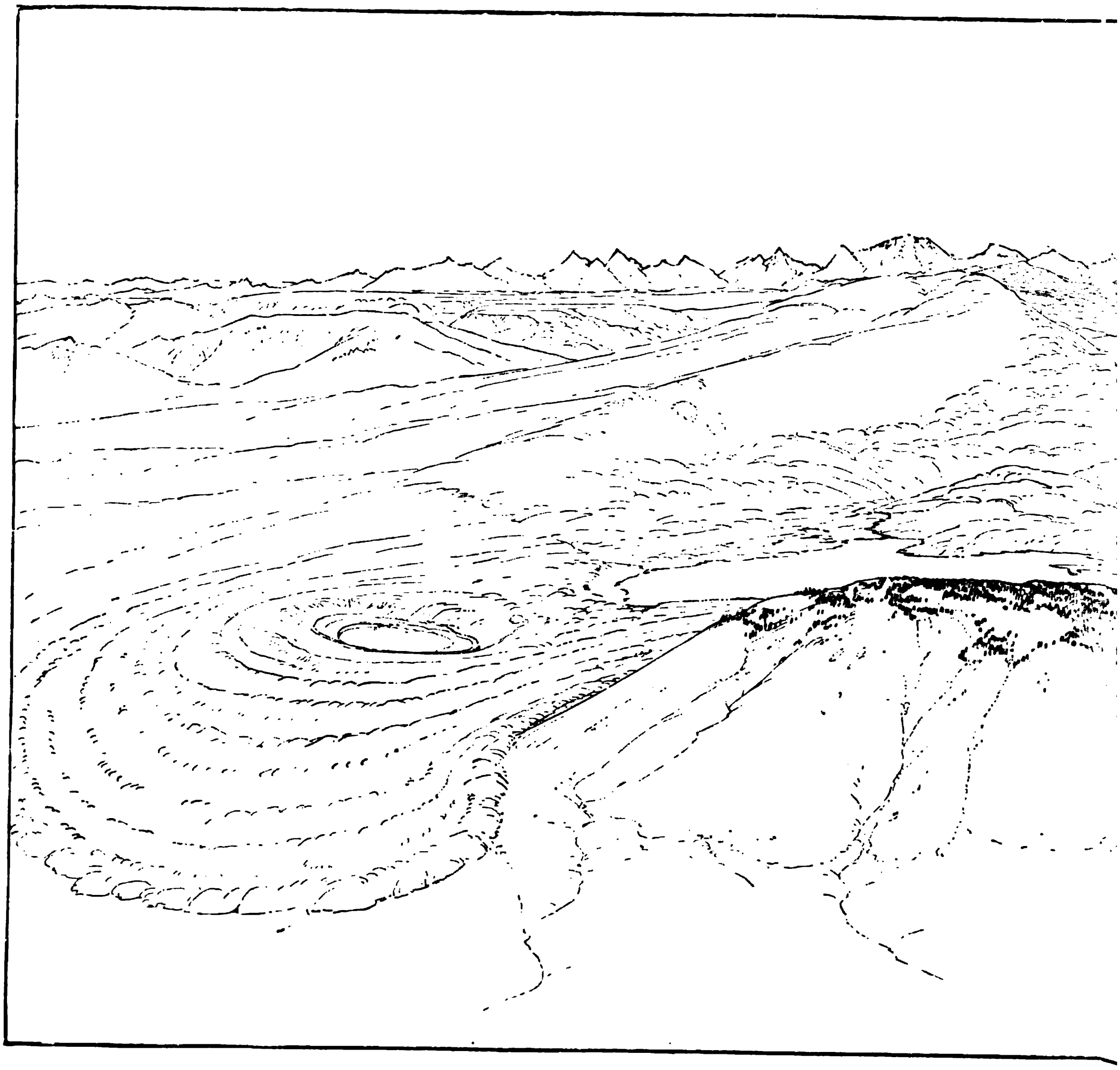
In the preliminary report of the Geological Survey of the Territories for 1878, in charge of F. V. Hayden, brief mention is made of existing glaciers on Wind River and Fremont's peaks, Wyoming, and a sketch of a glacier on Fremont's Peak is given in the atlas accompanying the annual report of the same survey for 1878; but no report of observations relating to these glaciers has yet been published. Mr. W. H. Holmes, one of the geologists of the exploring parties that visited the mountains of Wyoming under the direction of Prof. F. V. Hayden, has kindly contributed the following sketch of his experience among the glaciers still lingering in that region:

"The glaciers of the Rocky Mountains are few and insignificant. Formerly they were numerous and powerful and their deserted beds are found in every highland. The forms of the valleys and the sculpture of the mountains attest their former presence, and long lines of perfectly preserved moraines serve as a record of their magnitude.

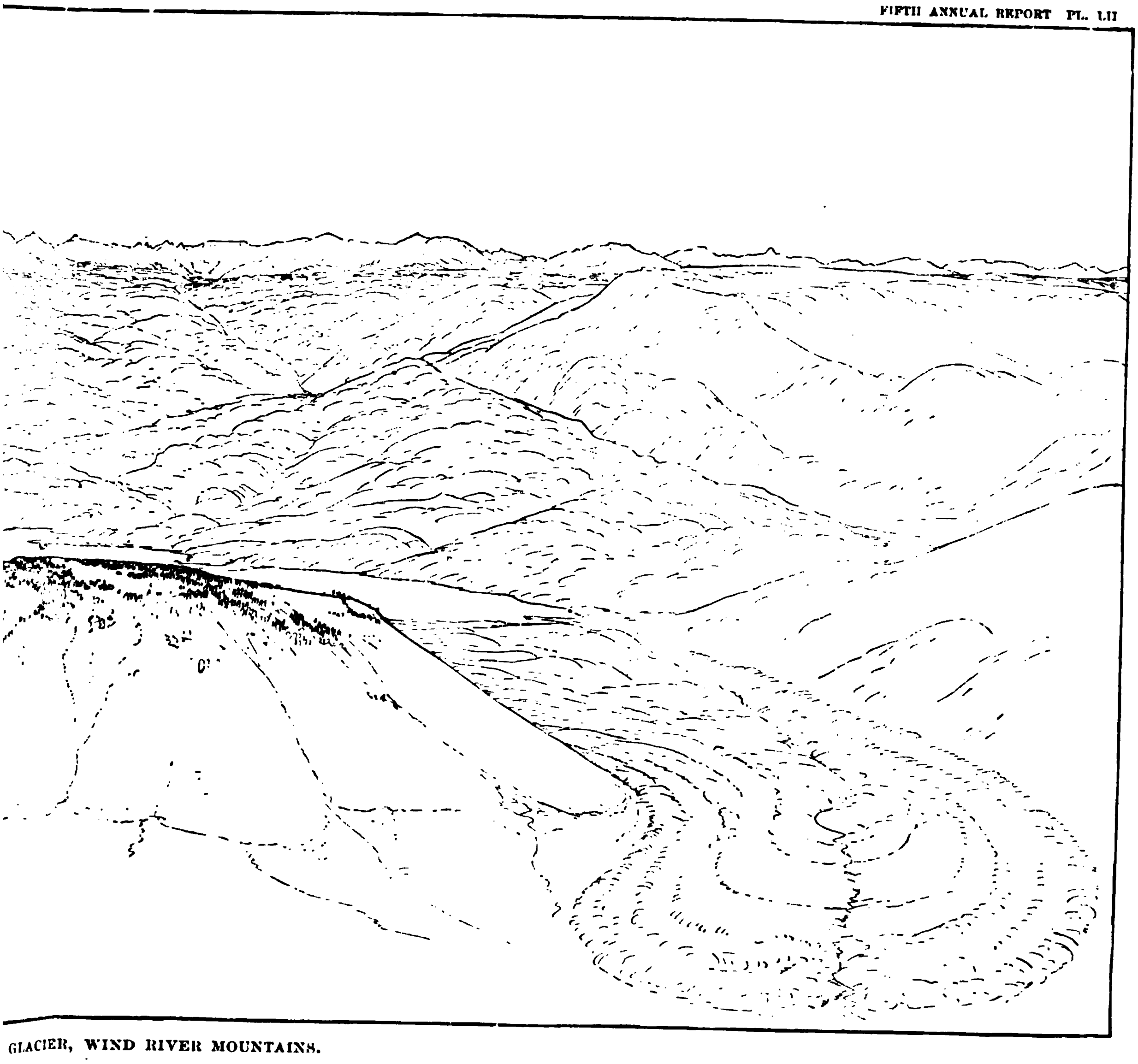
"There is but little evidence of general glaciation. The long even slopes stretching downward from the mountain fronts to the plains owe their conformation to other causes. It is only in the great valleys which descend from the central highlands that we find well-preserved traces of glaciers. In many of these the evidences of recent action are very striking yet we look in vain for great masses of snow or ice.

"In Colorado we followed up the valleys of the Platte, the Arkansas, the Rio Grande, and all the tributaries of the Colorado to the very crests of the ranges, but found nothing, save occasionally under the shadows of the loftiest summits, limited masses of compacted snow which could not be said to have movement and which in no case presented crevasses or ice fronts. The denuded gorges and the polished rocks of the steep upland slopes are only the pathways of avalanches, the offspring of the accumulated snows of a single winter.

"It was not until the summer of 1878 that I came upon what appeared to be a true glacier. This was in the Wind River Mountains of Wyoming. The season had been a dry one, and the snows of the preceding winter had, by the middle of July, almost wholly disappeared leaving



BED OF AN ANCIENT GLACIER



GLACIER, WIND RIVER MOUNTAINS.

exposed to view small fields of perpetual snow, with their well defined crevasses and terminal tongues of ice.

"In company with James Eccles, an Englishman, a geologist, and an Alpine climber, we ascended the most southerly of the great peaks of the Wind River Range. On reaching the crest from the southeast face I came suddenly out upon the brink of the vertical wall which forms the northern face of the peak, and, glancing over, I turned immediately around and shouted, "A glacier." I had looked for six years in vain for this phenomenon, and now experienced a decided feeling of gratification. As some of our party were doubtful as to the existence of glaciers in this region, we were doubly fortunate in having with us a gentleman familiar with the glaciers of the Alps, who, after making a careful examination, had no hesitation in pronouncing this a true glacier. Mr. Eccles published an account of his travels and studies in this region in the Alpine Journal for August, 1879.

"This glacier was of diminutive size, the whole mass of snow and ice being about 2,400 feet wide and less than a mile in length. It lies at the north base of the summit, and is shut in by a high, perpendicular wall which connects with the peak on the west and protects the *névé* field from the rays of the sun during the greater part of the day. The lateral walls are polished to their very crests, and the valley which opens out to the northeast bears the evidence of extensive glaciation as far down toward the plain as the eye could reach.

"From the summit of the peak we had a magnificent view along the serrated crest of the range to the northwest. The summits are generally rugged and sharp; but the high amphitheaters and valleys, although irregular in contour, have their granite faces rounded and polished until they fairly glisten in the sun. Many gem-like lakes are seen, resembling emeralds in their settings of living rock.

"The configuration of this range is well suited to the formation of glaciers. The mass of highland is very wide, and consists of a crest belt above 13,000 feet in height, bordered by a broad plateau from 10,000 to 12,000 feet in height. In past ages the crest has attracted the moisture, and great masses of snow have accumulated upon the broad upper surface of the plateau. This *névé* has given birth to a score of fine glaciers, which have descended by as many depressions in the southwest face of the plateau and deposited a magnificent system of moraines upon the plain below.

"At the end of the glacier-forming period, which may or may not have been synchronous with the glacial epoch, these ice-streams gradually retreated back up the face of the plateau, leaving concentric lines of morainal deposit, within which, at the base of the abrupt slope, we find a number of beautiful lakes.

"The broad polished roadways were finally abandoned entirely and now only limited patches of half solidified snow, the modern representatives of those ancient giants, nestle at the heads of the valleys in the shadows of the loftiest peaks.

"One of the most interesting of these glacier beds is shown in Plate LII. It happened in this case that the wide sheet of ice, on descending the steep face of the plateau and reaching the plain, encountered an outlying granite hill which stood directly in its way. The mass of ice, accumulating behind the hill, sent out branches to the right and left, finally encircling its base and extending a mile or more out upon the plain. The sketch was made from the southeastern end of this hill, but in order to give a more comprehensive view I have, in making the illustration, assumed a point of view sufficiently distant to take in the hill and the full series of moraines.

"A fine lake occupies the depression behind the hill, the drainage of which is by the left arm into the "new fork" of Green River. No map of this locality has yet been made. The moraines are extremely well defined, remaining just as perfect as when deserted by the ice. The concentric terminal lines are wonderfully well preserved, especially in the western branch, where they inclose the small deep lake shown in the view. The lateral moraines which lie up against the face of the plateau are not so well defined as in other cases farther up and down the range where they often exceed 1,000 feet in height. A number of these glaciers have been as much as 20 miles in length.

"In making the ascent of Fremont's Peak we passed up the plateau between the valley just described and that of Fremont's Creek to the north. The part of the plateau lying about the immediate base of the mountain presents the appearance of very recent glaciation, yet there is very little snow to be seen. The opposite side of the crest of the range is much more favorably located for the preservation of snow, and from the summit of Fremont's Peak we discovered a number of small glaciers. These occupy the deep circular amphitheaters immediately under the summits of the Fremont group, and were so far below us that no one ventured down upon them. The snow fields were very large, and about the upper margins showed a number of wide and deep crevasses. Toward the lower ends, which were somewhat obscure from our point of view, were evidences of the movement of the ice, and the extremities were encircled by concentric moraines. I have published a panoramic view of these glaciers in the Twelfth Annual Report of the Hayden Survey. Further exploration in this region will doubtless bring to light other living glaciers.

"The Teton Mountains have formerly given origin to a number of fine glaciers, as demonstrated by extensive morainal deposits on both sides of the range. A number of small glaciers still exist, but in no case have they been closely examined. There are great masses of snow visible about the summits north of the Grand Teton or Mount Hayden, and it is probable that good examples of living glaciers will be found there.

"In passing up the Snake River Valley on the east side of Jackson's Lake I observed that in the deep gorges of the eastern and northern faces of Mount Moran there were at least three small but well-devel-

[illegible]

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[illegible] Fremont's Peak we passed up the [illegible] and that of Fremont's Creek to the [illegible] lying about the immediate base of the [illegible] evidence of very recent glaciation, yet there [illegible]. The [illegible] the crest of the [illegible] needed for the preservation of snow, and [illegible] Fremont's Peak we observed a number of small [illegible] deep cirques, [illegible] heads of these [illegible] and were so nearly [illegible]. The snow fields were very large, and [illegible] showed a number of wide and deep crevasses. [illegible] which were somewhat obscure from our point [illegible] evidences of the movement of the ice, and the extremities [illegible] by concentric moraines. I have published a panorama [illegible] these glaciers in the Twelfth Annual Report of the Hayden [illegible]. Further exploration in this region will doubtless bring to light [illegible] living glaciers.

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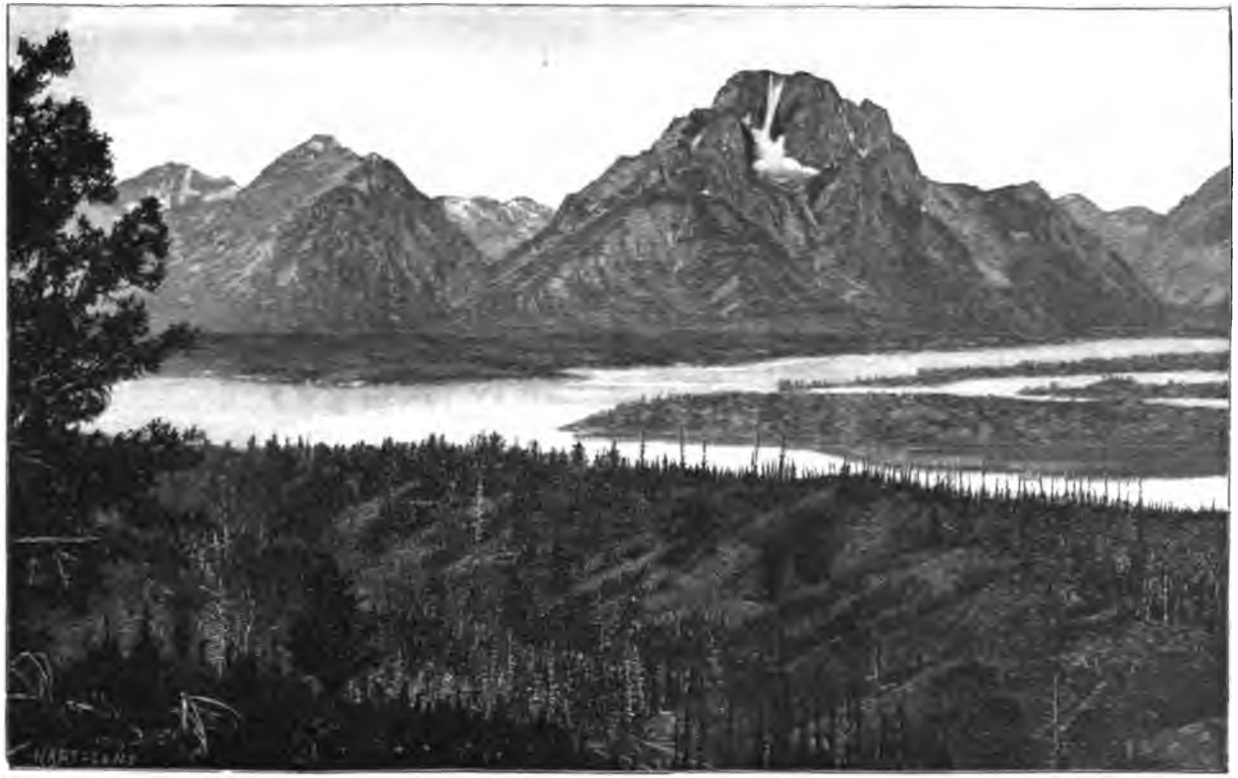

MOUNT MORAN, TETON RANGE, WYOMING.

oped glaciers. The illustration given in Plate (LIII) is from a sketch made through my field-glass, and shows the best example. The area of snow is exceedingly small, but the tongue of ice is well developed, and numerous crevasses expose the fine bluish-green color of the ice. Exposed to the rays of the sun this glacier would disappear in a very few years. The lower extremity of the ice is about 11,000 feet above the sea. The other examples were not so distinctly seen and are not of any great extent.

"The high ranges and plateaus of the Yellowstone country have undergone extensive glaciation, but I was unable to discover anything approaching a glacier in appearance, even in the center of the great mass about the sources of Clark's Fork and the Rosebud."

Existing glaciers were discovered by Professor Pumpelly during the progress of the transcontinental survey, at the head of the Flathead River in northern Montana. No scientific account of these observations has yet been published; but I am informed by Professor Pumpelly that two glaciers were seen in the mountains in which the East Fork of the Flathead rises at an elevation of about 7,000 feet. It was observed that the glaciers broke off suddenly at the summit of precipices 2,000 feet high, and that the waters flowing from beneath the ice had the milky color characteristic of glacial streams. The mountains in which these glaciers were discovered extend northward into British America, and are supposed to reach their greatest elevation north of the boundary. It seems safe to predict that when this little-known region is more fully explored additional glaciers will be found about the peaks known as the Crows and Mountain Head.

GLACIERS OF ALASKA.

In the purchase of Alaska the United States not only acquired a vast territory rich in many natural resources, but also added new wonders to her varied scenery and greatly increased her list of interesting natural phenomena. As the preceding pages show, the glaciers of the United States, previous to the purchase of Alaska, were by no means insignificant, although at that time almost unknown and even now but only imperfectly explored. When we include Alaska our field for glacial study becomes almost unlimited.

The glaciers of Alaska discovered up to the present time are all of the alpine type, except certain masses of buried ice of ancient date, which are probably remnants of accumulations that were formerly of great extent. All the true glaciers are confined to the southern portion of the territory, and evidently depend on topographic conditions for their geographic distribution. The mountains of Alaska occur mostly along its southern border, attaining their greatest elevation in the St. Elias Alps, distant less than 20 miles from the ocean. The entire Pacific border of Alaska is described by all who have explored it as being extremely rugged and mountainous. The same bold topography characterizes the Alaskan Peninsula, and is continued in the Aleutian Islands, which are in reality the peaks of a submerged mountain range. Northward of the imperfectly known Alaskan mountains, which traverse the territory in an easterly and westerly direction, the country is mostly low and not occupied by permanent snow or ice, except in the case of certain buried ice-masses to be mentioned farther on. The glaciers of Alaska occur in valleys and gorges amid the mountains, in the same manner as in similar localities in the Sierra Nevada, Rocky Mountains, etc.; but they are of vast dimensions, owing to the high latitude at which they occur and the abundant precipitation of the region.

In reviewing what has been written concerning the ice-fields of Alaska we find a want of detailed observations of glacial phenomena, but in their stead a number of general sketches and popular descriptions that indicate the richness of the field awaiting exploration. Besides newspaper accounts, always difficult of access, and too frequently wanting in scientific accuracy, there are only a few reports and essays to claim our attention.

The earlier voyagers to the shores of Alaska saw many bodies of ice, some of which we now know were glaciers. Sir Edward Belcher, in his account of the voyage of the "Sulphur," makes brief mention of cliffs of ice on the borders of Icy Bay, near the foot of Mount St. Elias, and states that the shores of the bay were composed of snow-ice to the depth of about 30 feet, which was thought to rest on a low muddy beach. At

Cape Suckling, a hundred miles westward of Icy Bay, similar phenomena were observed.

In the accounts of Vancouver's voyage[32] bodies of ice terminating in cliffs at the water's edge are mentioned as being numerous on the borders of Prince William Sound; and in the same narrative brief descriptions are given of an accumulation of ice in an arm of Stephens Passage, northwest of Sitka, and also among the mountains on the coast opposite Admiralty Island. Two large bays opening north and west from Point Couverdeen are described by Vancouver as terminating in solid mountains of ice rising perpendicularly from the water's edge. Beyond the simple fact of the presence of large masses of ice at the sea-level, the accounts of the earlier voyagers are of little service to the special student of glacial phenomena.

Some of the glaciers along the northern bank of the Stikine River, Alaska, were visited in 1863 by William P. Blake, who published a brief account of his observations in the American Journal of Science.[33] As this is the only account of the magnificent glaciers of the Stikine River region that has been published by a scientific observer, we take the liberty of transcribing it nearly entire:

"The principal stream in the vicinity of Sitka, is the Stickeen (Stikine); which rises in the 'Blue Mountains,' opposite the headwaters of the Mackenzie, and flows in a general southeasterly direction parallel with the coast until it breaks through the mountains east, and a little north, of Sitka. When the snows are melting, the river becomes much swollen, and is then navigable with difficulty by small steamboats for about 125 miles above its mouth. The valley is generally narrow and the river is not bordered by a great breadth of alluvial land.

"In ascending this river one glacier after another comes into view; all of them are upon the right bank of the stream and descend from the inner slope of the mountain range. There are four large glaciers and several small ones visible within a distance of 60 or 70 miles from the mouth.

"The first glacier observed, fills a rocky gorge of rapid descent, about 2 miles from the river, and looks like an enormous cascade. The mountains are greatly eroded by it, for it is overhung by freshly broken cliffs of rock evidently produced by the glacier.

"The second glacier is much larger, and has less inclination. It sweeps grandly out into the valley from an opening between high mountains from a source that is not visible. It ends at the level of the river in an irregular bluff of ice, a mile and a half or two miles in length, and about 150 feet high. Two or more terminal moraines protect it from the direct action of the stream. What at first appeared as a range of ordinary hills along the river, proved on landing to be an ancient terminal moraine, crescent-shaped, and covered with a forest. It extends the full length of the front of the glacier. The following extract from my notes will answer for a description of the end of this glacier.

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[32] Vol. III, p. 185 (1774). Quoted by Blake, Amer. Jour. Sci., Second series, Vol. XLIV, p. 101.

[33] Vol. XLIV, p. 96–101 (1867). Published also, with a map, in a report to the Secretary of State, "Geographical Notes upon Russian America and the Stickeen River. Washington, 1868."

"We found the bank composed of large angular blocks of granite mingled with smaller fragments and sand. It is an outer and older moraine, separated from a second one by a belt of marsh, and overgrown with alders and grass, and interspersed with ponds of water. Crossing this low space we clambered up the loose granitic débris of the inner moraine, which is quite bare of vegetation and has a recently formed appearance. These hills are from 20 to 40 feet high, and form a continuous line parallel with the outer and ancient moraine. From their tops we had a full view of the ice cliffs of the end of the glacier rising before us like a wall, but separated from the moraine by a second belt of marsh and ponds. Here, however, there were no plants or trees. It was a scene of utter desolation. Great blocks of granite lay piled in confusion among heaps of sand or sand-cones, or were perched upon narrow columns of ice-glacier tables apparently ready to topple over at the slighest touch. The edges of great masses of ice could be seen around pools of water, but most of the surface was hidden by a deposit of mud, gravel and broken rock. It was evident, however, that all this was upon a foundation of ice, for here and there it was uplifted, apparently, in great masses leaving chasms filled with mud and water. Over this fearful and dangerous place we crossed to the firmer and comparatively unbroken slope of ice at the foot of the bluff, and afterwards had to climb over snow and ice only, in the attempt to reach the top of the glacier. From below it had appeared to us to be quite possible to accomplish this if we followed the least broken part of the slope, but it

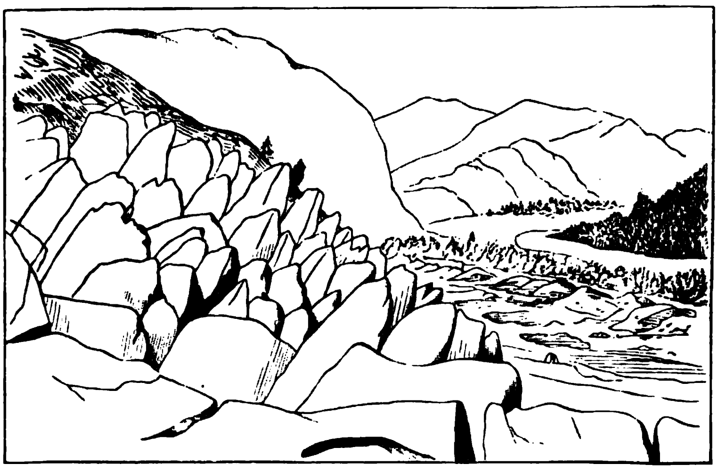

FIG. 141.—End of glacier, looking northwest.

proved to be difficult, and finally impossible. Fissures which could not be seen from a short distance were met at intervals, some of them being so wide that we were forced to turn aside. As we ascended, the crevasses were more numerous but were generally filled with hard snow to which we occasionally trusted. The surface soon became precipitous and broken into irregular stair-like blocks with smooth sides and so large that it was impossible to make our way over them without ladders or tools to cut a foothold. Here we turned and enjoyed the sight of this great expanse of ice, broken into such enormous blocks and ledges. The sun illuminated the crevasses with the most beautiful aquamarine tints, passing into a deep sea-blue where they were narrow and deep. In one direction the ice presented the remarkable appearance of a succession of cones or pyramids with curved sides. In the opposite direction and at the same level the outlines were totally different, showing merely a succession of terraces or steps inclined inward toward the glacier and broken by longitudinal crevasses.

"The annexed sketches were made from this point of view. Fig. 141 is taken looking up the river over the end of the glacier, and shows the pyramids of ice. The line of ponds and the two moraines are seen at the base and the river on the extreme right. Fig. 142 shows the appearance of the glacier in the opposite direction.

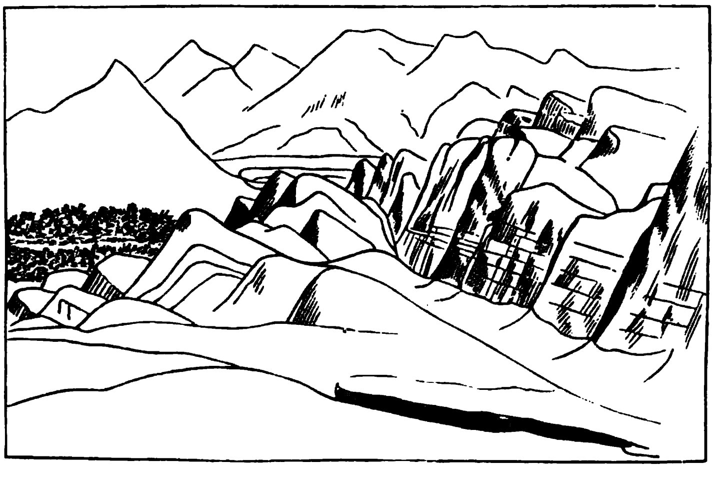

FIG. 142.—End of glacier, looking southeast.

"A broad fissure between one level of the ice and the next is filled with snow.

"It is evident that this glacier breaks down in a series of great steps or ledges along the greater part of its front. These steps rise for 20 to 30 feet one above the other, and thus produce a stair-like ascent, while at the same time the numerous parallel fissures at right angles break the surface into rectangular blocks, which on the side exposed to the sun soon become worn into the pyramids and cones. The difference of outline in opposite directions is thus explained.

"I was inclined to regard the melting action of the water of the river as the cause of this abrupt breaking off of the end of the glacier. There may, however, be a sudden break in the rock foundation at this point, so as to produce an ice-cascade. The following section will perhaps give a clearer idea of the manner in which the glacier breaks down.

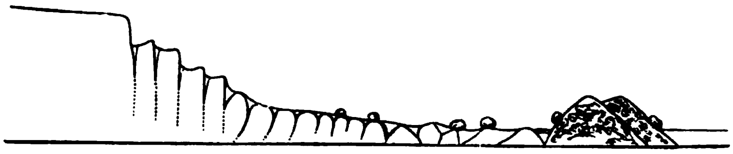

FIG. 143.—Section of end of glacier.

"One or more streams descend under the glacier, and reach the river at different places. The rushing and roaring sound was rather startling at some of the crevasses.

"Judging from the number of loose blocks of rock at the foot of the glacier, the upper surface must be strewn with them, but this could not be verified by observation. Time did not permit a more extended examination. There would be little difficulty in gaining the surface of the glacier from the side, and, perhaps, at some other points along its front. It was impossible to get our Indian guide to accompany us. They have a tradition of the loss of one of their chiefs upon this glacier.

"The ancient terminal moraine of this glacier is significant of an amelioration of the climate. It is also interesting to note the effect which this accumulation of materials from the glacier has had upon the river. It has acted as a dam for the waters, setting them back into the valley for some distance."

An essay from the pen of W. H. Bell, on the Stikine River and its glaciers, appeared in Scribner's monthly for April, 1879, accompanied by a number of illustrations of remarkable scenery. This article, although well worth reading, is diffuse and too popular for scientific accuracy, and its illustrations are sketchy and too greatly exaggerated vertically to be admitted as truthful representations of natural scenery.

The accompanying pictures of the Bernardo and Orlebar[34] glaciers which we have introduced as illustrations of the wonderful glacial scenery of the Stikine River, are direct reproductions from photographs taken by Mr. E. Dossetter, under the direction of Lieut. Col. J. W. Powell, superintendent of Indian affairs of British Columbia. The photographs were kindly placed at the service of the Geological Survey by the director of the American Museum of Natural History.

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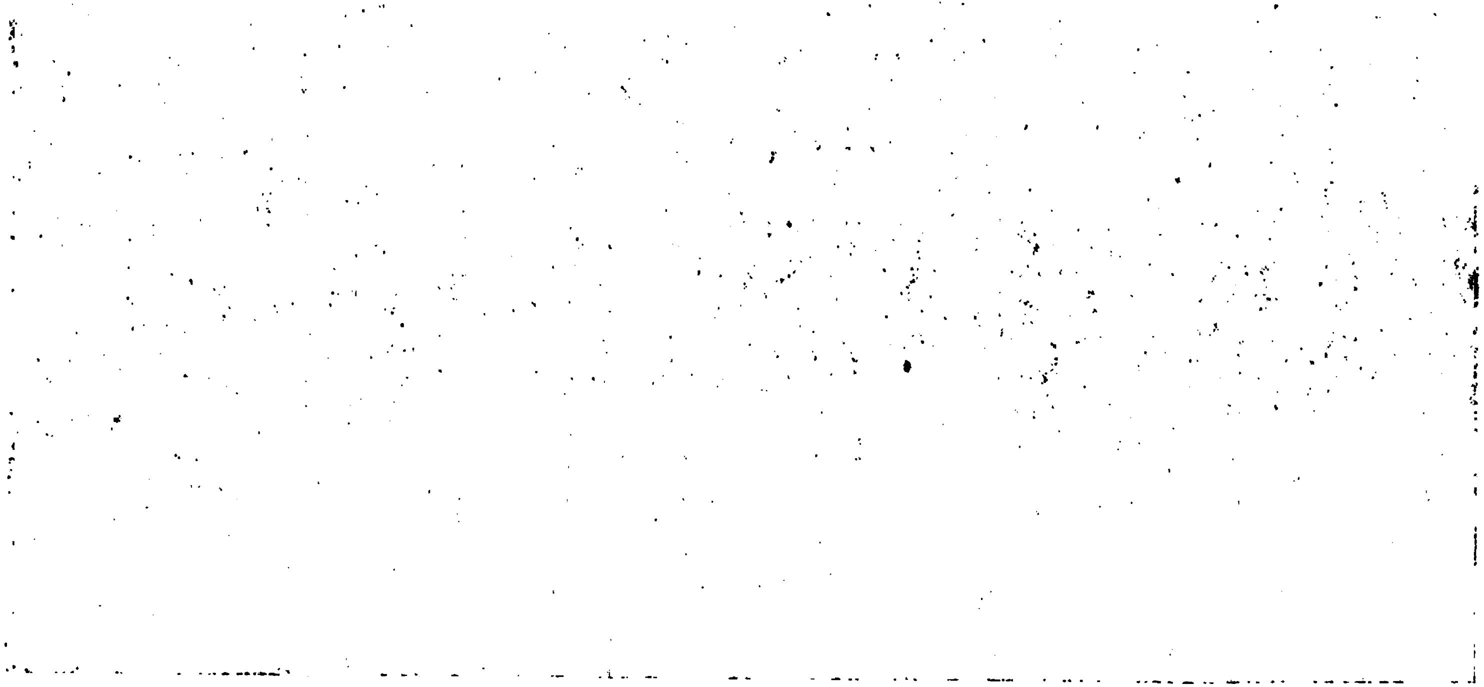
[34] The location of these glaciers not being given on the photographs, the writer has been unable to correlate them with the descriptions and illustrations published by Blake and others.



[illegible] GLACIER, STIKINE RIVER, ALASKA [illegible] This [illegible]

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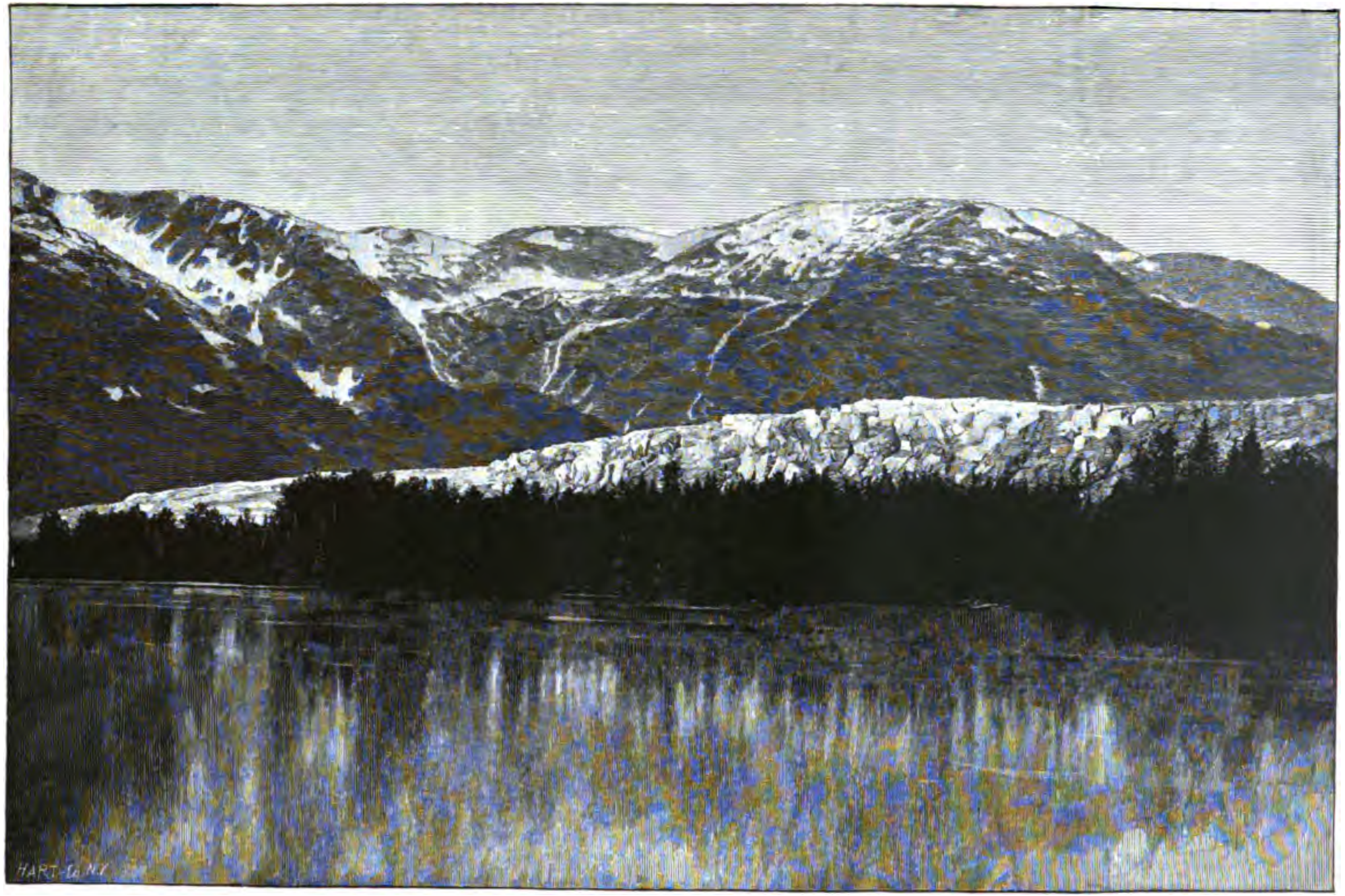

ORLEBAR GLACIER, STICKINE RIVER, ALASKA.

Along the shore of the mainland north of the mouth of the Stikine River (approximate latitude 56° 40′) glaciers are reported as occurring on the coast east of Admiralty Island, and will probably be discovered along the Taka River, which, like the Stikine, breaks through a mountainous region near the coast. A number of glaciers, some of which are of great size, occur along the precipitous shores of Glacier Bay and Lynn Canal.[35] Fortunately the positions of these glaciers have been indicated with accuracy on the maps of the U. S. Coast Survey, prepared under the direction of W. H. Dall.

From the head of Lynn Canal a pass leads northwestward to the headwaters of the Yukon, which was followed in 1883 by the military reconnaissance in charge of Lieut. F. Schwatka, who reports four glaciers between Chilcoot Inlet and Lake Lindeman.[36]

Northwestward from Cross Sound, which connects the land-locked waters of Glacier Bay and Lynn Canal with the ocean, the mountains near the coast form a rugged and mostly unexplored chain, giving birth to numerous glaciers. Those flowing toward the ocean have been mapped by Dall, and their positions have been indicated on the charts of the Coast Survey.[37] From the same authority we learn that a number of extensive ice-bodies have been seen on the southern slope of the mountains connecting Mount Vancouver with Mount St. Elias. The northern slopes of these mountains are entirely unexplored. Four more large glaciers have been mapped by Dall on the Kenai Peninsula,[38] projecting from the southern coast in latitude 60° longitude 150°. From this region the general trend of the Alaskan coast is southwestward, the direction being given by the Alaskan Peninsula and the Aleutian Islands. On the peninsula a glacier is reported by Dall as far westward as longitude 162°,[39] and on the Aleutian Islands a small one was discovered by George Davidson[40] on the island of Unalaska at an altitude of about 2,000 feet above the sea, the limit of perpetual snow being 1,000 feet higher. What the extreme westerly limit of the Alaskan glaciers may be remains to be determined.

As will be seen from this brief sketch, nearly all the glaciers reported are near the coast; in fact, the greater part were discovered from the decks of vessels. When exploration is carried inland with the thoroughness and accuracy that characterize Dall's survey of the coast, it cannot fail to extend greatly our knowledge of glacial phenomena. A thorough exploration of the St. Elias Alps is especially important in this connection.

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[35] Notes on Glaciers in Alaska, by Thomas Meehan, Proc. Acad. Nat. Sci. Philadelphia, November 6, 1883.

[36] Science, Vol. III, 1884, p. 220.

[37] Chart No. 751.

[38] Chart No. 766.

[39] Coast Survey Chart No. 806.

[40] U. S. Coast Survey Report, 1867, p. 211.

In writing on present glaciation in Alaska,[41] Dall has called attention to the great differences in the character of the ice-masses observed by him during nine years of exploration. To use his own words—

"These might be classed under several heads: as plateau-ice, filling large areas of depression and without motion as a whole, but when sufficiently accumulated, overflowing the edges of its basin in various directions; as valley-ice, filling wide valleys of gentle incline both as to their axes and their lateral slopes, producing masses of ice moving in a definite direction, but without lateral and sometimes even without terminal moraines; as ice-cascades, formed in sharp narrow ravines of very steep inclination, usually without well-defined surface moraines; as typical glaciers, showing névé and lateral and terminal moraines; and lastly, as effete or fossil glaciers, whose sources had become exhausted, whose motion had therefore ceased, and whose lower portions have become smothered by the accumulation of non conducting *débris*. The very existence of one of these last has remained unknown for half a century, though the plateau under which it is buried has been described and mapped by explorers.

"Another form under which ice appears in Alaska is that of solid motionless layers, sometimes of great thickness, interstratified with sand, clay, etc. * * * * * This formation, in which ice plays the part of a stratified rock, extends from Kotzebue Sound [on the west coast of Alaska, at the Arctic circle], where the greatest known thickness of the ice-layer, about 300 feet, has been noted, around the Arctic coast, probably to the eastern boundary. In Kotzebue Sound the ice is surmounted by about 40 feet of clay containing the remains of fossil horses, buffaloes (*Bos latifrons*, etc.), mountain sheep, and other mammals. Farther north the ice is covered with a much thinner coat of mineral matter or soil, usually not exceeding 2 or 3 feet in thickness, and rarely rising more than 12 or 15 feet above high water mark on the sea coast. Its continuity is broken between Kotzebue Sound and Icy Cape by rocky hills composed chiefly of carboniferous limestones, which bear no glaciers and do not seem to have been glaciated. The absence of bowlders and erratics over all this area has been noted by Franklin, Beechy, and all others who have explored it."

A more extended account of the buried ice-masses at Kotzebue Sound was published by Dall in the American Journal of Science,[42] in which the occurrence of the bones of extinct mammals in the clay covering the ice is more fully described. The deposits above the ice in many places had a strong odor of decaying animal matter, which was believed to originate from the remains of the soft parts of the mammoth and other animals whose bones were daily washed out by the sea from the clay talus that fringes the ice-cliffs.

As described in the article mentioned above, the formation of the sur-

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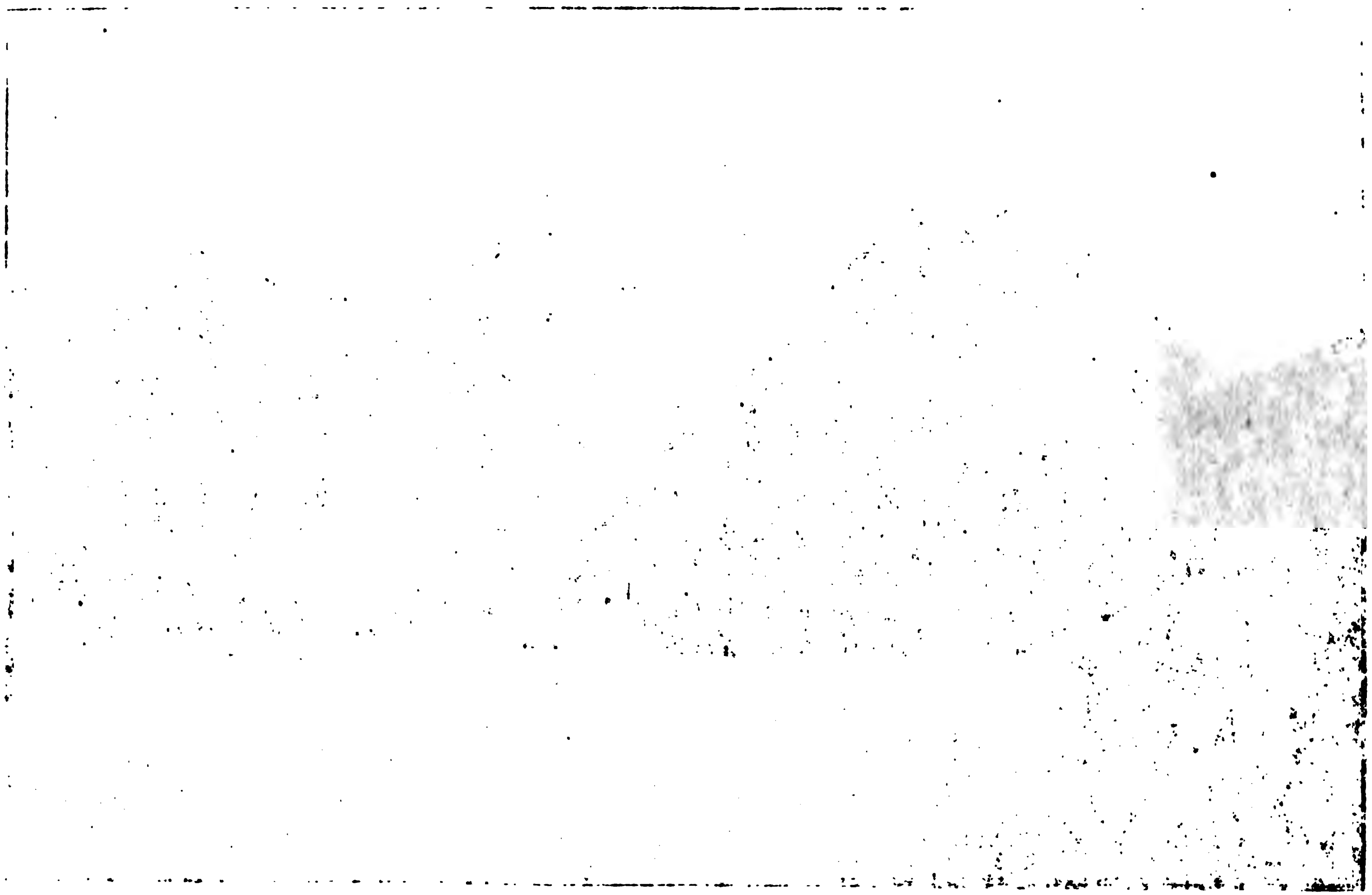
[41] Bulletin of the Philosophical Society of Washington, Vol. VI, p. 33.

[42] Vol. XXI, third series, 1881, p. 108.



BERNARD GLACIER, STIKINE RIVER, ALASKA.

[illegible] great glaciers on south Alaska [illegible] Dall [illegible] Patterson [illegible] the characters of the ice masses observed [illegible] exploration. These [illegible] several kinds: [illegible] and [illegible] as a whole, but [illegible] masses of ice [illegible] lateral and sometimes even without [illegible] as ice cascades, found in sharp narrow ravines of [illegible] well defined surface moraines; [illegible] and lateral and terminal moraines [illegible] of fossil glaciers, whose sources had been [illegible] had therefore ceased, and whose lower portions [illegible] by the accumulation of [illegible] one of these last has remained unknown [illegible] though the plateau under which it is buried has been [illegible] and mapped by explorers.

"Another form under which ice appears in Alaska is that of solid moundless layers sometimes of great thickness, interstratified with sand, clay, etc. * * * * * This formation, in which ice plays the part of a stratified rock, [illegible] Kotzebue Sound [illegible] the west coast of Alaska, [illegible] where the greatest known thickness of the ice layer, [illegible], has been noted, around the Arctic coast, probably to the [illegible]. In Kotzebue Sound the ice is surmounted by [illegible] the remains of fossil horses, buffaloes (*Bos* [illegible]), mountain sheep, and other mammals. Farther north the [illegible] covered [illegible] a much thinner coat of mineral matter or soil, usually not exceeding 2 or 3 feet in thickness, and rarely [illegible] more than 12 or 15 feet [illegible] on the sea coast. Its continuity is broken between [illegible] and Icy Cape by rocky cliffs composed [illegible] limestones, which bear no glaciers [illegible] not seem to have been glaciated. The absence of bowlders and [illegible] noted by Franklin, Beechy, and all [illegible] who have explored it."

[illegible] account of the buried ice-masses at Kotzebue Sound [illegible] Dall in the American Journal of Science,[2] in which [illegible] the bones of extinct mammals in the clay covering [illegible] described. The deposits above the ice in many places [illegible] decaying animal matter, which was believed to [illegible] remains of the soft parts of the mammoth and other [illegible] were daily washed out by the sea from the clay [illegible].

[illegible] mentioned above, the formation of the su-

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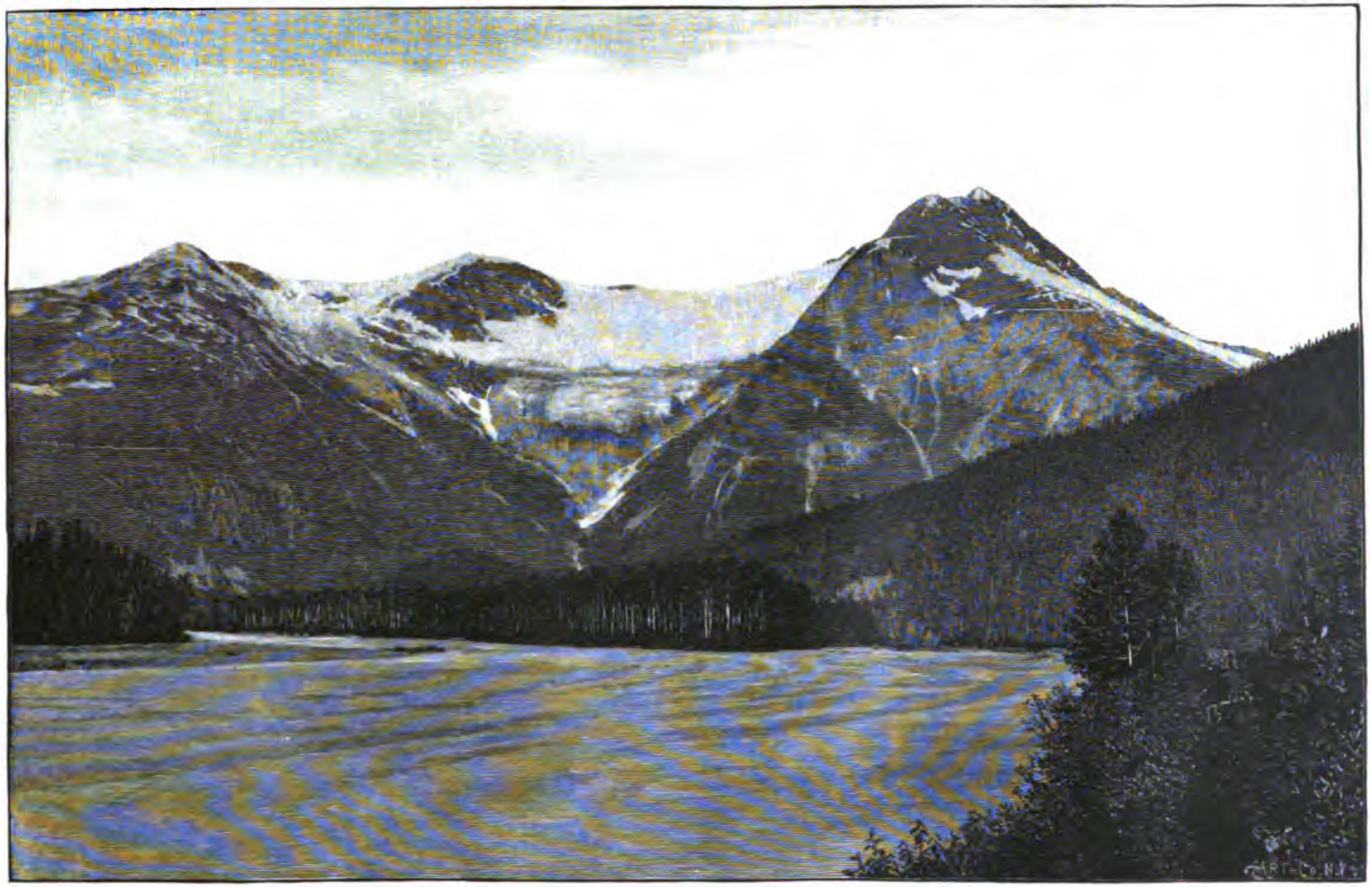
[1] [illegible] Society of Washington, Vol. VI, p. 33.

[2] [illegible] p. 198.



BERNARD GLACIER, STICKINE RIVER, ALASKA.

rounding country shows no high land or rocky hills from which glaciers might have been derived and then covered with *débris* from the sides. The continuity of the mossy surface shows that the ice must be quite destitute of motion, and the circumstances appear to point to the conclusion that there is here a ridge of solid ice rising several hundred feet above the sea, higher than any of the land about it, older than the mammoth and the fossil horse, and taking upon itself the functions of a regular stratified rock.

A review of the results attained up to the present time in the exploration of the ice-bodies of the United States, shows that we have examples of a great variety of glaciers. Beginning at the south, in the southern portions of the Sierra Nevada, Basin Ranges, and the Rocky Mountains, we find numerous snow-banks and ice-masses that last throughout the summer, but which do not exhibit the characteristics of true glaciers. Farther northward in the Sierra Nevada and Rocky Mountains there is a large number of small glaciers of the Alpine type that have all the peculiar features pertaining to more typical ice-streams. Crowning the hoary giants of the Cascade Mountains are numerous glaciers, flowing through narrow defiles and over precipices by no means unworthy of comparison with the classic ice-fields of Switzerland and Scandinavia. In Alaska the catalogue is still farther extended, embracing numerous examples of Alpine glaciers as magnificent as any in the world. In addition, there are remnants of fossil glaciers that appear to have existed since the glacial epoch—older, certainly, than the now extinct Quaternary mammals which formerly roamed over this continent. Glaciers of the continental type, like those of Greenland, are alone wanting to complete the category.